Department of Planning and Environment

Mapping the natural blue grid elements of Wianamatta–South Creek

High ecological value waterways, riparian vegetation communities and other water dependent ecosystems

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Cover photo: Unnamed tributary of Little Creek, Shanes Park. Carl Tippler

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1. Protected to the most insignificant jet

‘On 28 August 1826 a truly remarkable public meeting was held in Windsor Courthouse attended by notable local Aboriginal figures of the day. In this remarkable meeting it was resolved “that the rivers be protected to the most insignificant jet”, a poignant resolution still pertinent for the waters of the Wianamatta system.

Water resources have important cultural, spiritual, and practical values for First Peoples. Waterways are crucial for cultural practices and knowledge transfers as part of a healthy, flowing, connected system.

The Cannemegal and Wianamattagal peoples of the Dharug nation still care for the Country of Wianamatta and carry the stories and knowledges of that landscape. Dharug Elders describe Wianamatta as an interconnected system, formed through the Dreaming, this cultural landscape connects from beyond the mountains out to the sea. It is a particularly important place for pregnant women as the place of the mother creek – a female landscape relating to motherhood and creation.

The floodplains of Wianamatta remain a significant place for Aboriginal communities. South, Ropes, Badgerys, and Thompsons Creeks form a major part of the Aboriginal infrastructure which has provided resources such as food, medicine, and recreation over thousands of generations of people. It is imperative to respect these waterways and their dynamic movements, and to learn from their capacity to find the path of least resistance. Allowing one part to become ill through pollution, mismanagement or overuse will cause the whole system to suffer. All the waters must be protected to ensure the health of the whole system – to the most insignificant jet.’

Dr Danièle Hromek is a Budawang woman of the Yuin nation – she has spent some time yarning with the Aboriginal Elders in Wianamatta to help translate cultural values into land-use planning

2. About this document

This document describes the background and methods for developing a map of the natural blue grid in the Wianamatta–South Creek catchment. The natural blue grid forms part of the essential infrastructure requirements for delivering the Western Parkland City. It is made up of waterways, riparian vegetation communities, wetlands, and other water dependent ecosystems.

This document provides examples of how the map has been used to support the strategic planning of the Western Parkland City. It is a technical document, but it is intended for strategic planners and practitioners who may require the scientific evidence base for including the map in various planning instruments and studies. There are several large appendices at the end of the document to provide more detail on the spatial data, fieldwork, modelling and analyses used in the mapping.

The document provides the technical background for the NSW Government *Performance criteria for protecting and improving the blue grid in Wianamatta–South Creek catchment* (DPE 2022a). It is part of a series of technical documents that have been released by the NSW Government to support precinct planning in Western Sydney:

- *Performance criteria for protecting and improving the blue grid in the Wianamatta–South Creek catchment* (DPE 2022a)
- *Wianamatta–South Creek stormwater management targets* (DPE 2022b)
- *Review of water sensitive urban design strategies for Wianamatta–South Creek* (DPE 2022c)
- *Technical guidance for achieving Wianamatta–South Creek stormwater management targets* (DPE 2022d).

3. Background

Wianamatta–South Creek is located on the Cumberland Plain in Western Sydney, Australia. It is characterised as a floodplain with a network of perennial and intermittent flowing tributaries that collectively drain into the larger Hawkesbury–Nepean River system (Figure 1). Over the next 40 years much of the creek's catchment will be urbanised to become part of the Western Parkland City, and home to over 1.5 million people (GSC 2018).

The Western Parkland City is one of 3 cities described in the Greater Sydney Commission's Region Plan (A Metropolis of Three Cities), which is currently guiding planning and investment decisions on future housing, economic development and jobs in Greater Sydney. Unlike the other 2 cities, the Western Parkland City will be a new city centred around a new international airport. Considerable strategic planning of the urban footprint is underway to ensure the Greater Sydney Commission's visions for the Western Parkland City are delivered. One strong vision is for Wianamatta–South Creek (and its tributaries) to become a cool green corridor through the Western Parkland City and be the core element of liveability and amenity for the residents. This vision relies on urban planners to explicitly integrate waterways into the design of the city and residential neighbourhoods, and for the waterways and other water dependent ecosystems to be healthy so they can provide the essential services and functions expected of a cool green corridor.

Currently, the Wianamatta–South Creek catchment is described as the most degraded catchment in the Hawkesbury–Nepean River system (H–N CMA 2007; DECCW 2010a; BCC 2021; LCC 2021). Historical vegetation clearing and urbanisation have significantly altered the hydrological and sediment regimes of the catchment, which in turn have altered the geomorphology and ecology of the waterways. This is reflected in recent river health assessments (AUSRIVAS, River Styles), which categorise Wianamatta–South Creek and its tributaries as being significantly or severely impaired (Figure 1). As recognised in the Greater Sydney Commission's Region Plan, urbanisation of the Wianamatta–South Creek catchment has the potential to further degrade the waterways if stormwater, wastewater, and flooding regimes are not managed upfront through an integrated ecosystems or landscape led approach. This approach requires the waterways and hydrological cycle to be central considerations in both land-use and water infrastructure planning. This approach differs from current land-use planning practices, which are mostly fragmented and based on post hoc solutions that do not consider the broader catchment context and function. As described in a growing body of international literature, an integrated ecosystems or landscape led approach to urban planning will result in sustainable, resilient and liveable cities; for example, Rotterdam (Frantzeskaki and Tilie 2014) and Singapore (Rowe and Lee 2019).

In this present study, our specific objective was to create a map showing strategic planning priorities for protecting and improving the health of high ecological value waterways, riparian vegetation, and other water dependent ecosystems in the Wianamatta–South Creek catchment. Collectively, these natural elements are recognised as part of the Blue and Green Infrastructure Framework for the Western Parkland City, and as such, have been key considerations in the design of the Aerotropolis (WSPP 2020).

The need for the map (and hence this study) originated from 2 whole-of-government initiatives that sought to protect and restore the waterways, riparian vegetation, and other water dependent ecosystems in the Wianamatta–South Creek catchment. The purpose of the first initiative was to develop the South Creek Corridor Strategy, to meet the requirements of a sectoral review under the *Infrastructure NSW Act 2011* (INSW 2019). The map was used to inform the Strategic Options Business Case for Stage 1 of the review, specifically addressing Infrastructure NSW's objective of 'Protect and enhance high value environmental resources (flora, fauna, habitat, waterways), with due regard to the need for environmental connectivity along South Creek and its major tributaries'.

The second initiative is part of an overarching Marine Estate Management Strategy 2018–2028 (MEMS) for the NSW Government to coordinate the management of the marine estate in accordance with the objects of the *Marine Estate Management Act 2014*. Outflows from the Wianamatta–South Creek catchment to the Hawkesbury–Nepean River are the largest within the system and have been identified as a key threat to the way the local communities value and use the waterways in the area. The map has directly informed 2 management actions under the MEMS related to implementing the NSW Government *Risk-based framework for considering waterway health outcomes in strategic land-use planning decisions* (the Risk-based Framework; Dela-Cruz et al. 2017) in the Wianamatta–South Creek catchment. This Risk-based Framework has been recognised in the Greater Sydney Commission's Region Plan (and supporting district plans) as an approach to managing cumulative impacts of urban development and improving the health of catchments and waterways. The planning priorities identified in the map have since been used to inform waterway health objectives, which are needed to implement the first step of the Risk-based Framework, and have guided strategic planning criteria and benchmarks for protecting and restoring the natural blue grid and reducing stormwater and wastewater impacts on Wianamatta–South Creek and its tributaries (DPE 2022a).

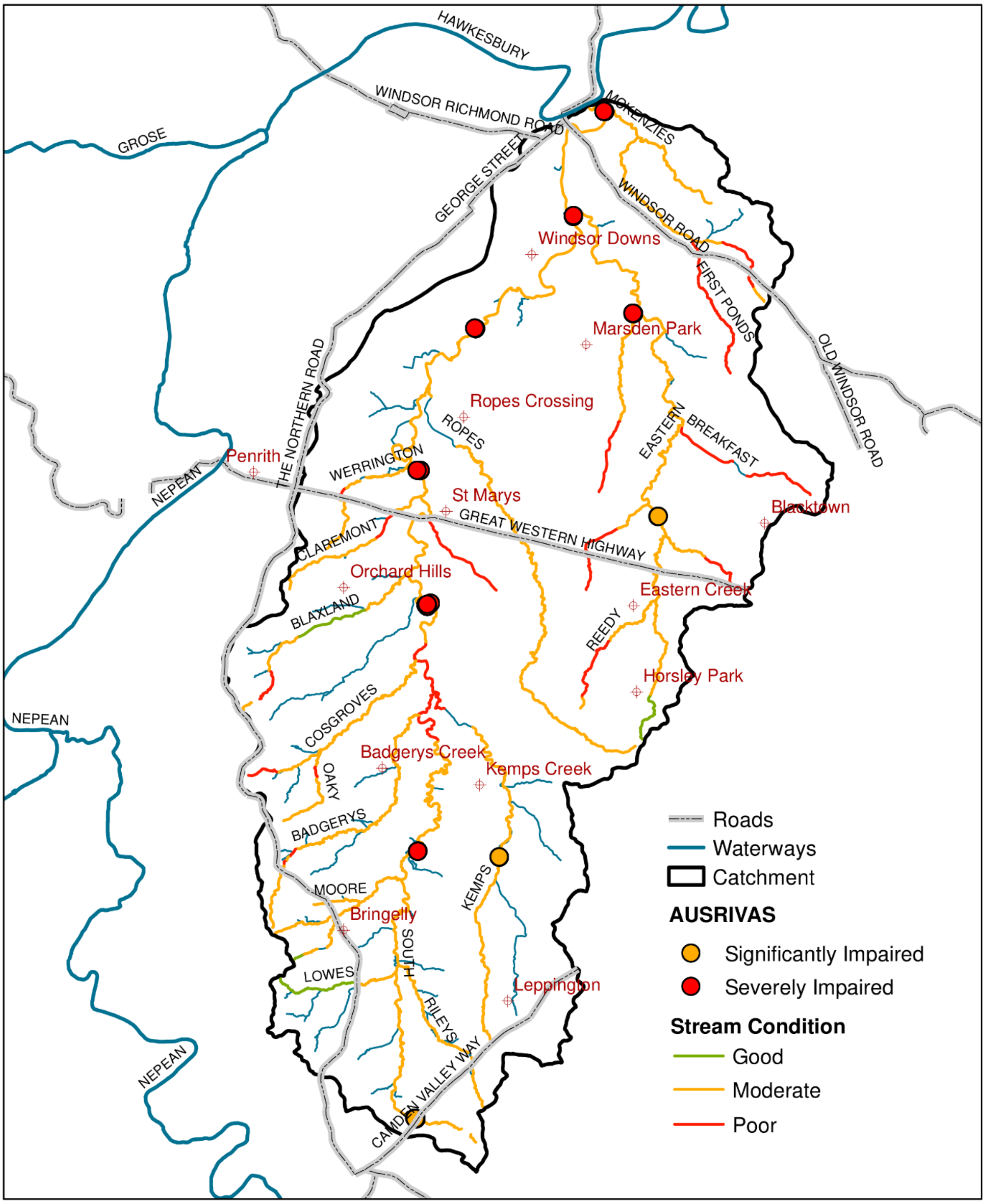

Figure 1 **Wianamatta–South Creek catchment and ecological condition of major tributaries based on AUSRIVAS and River Styles assessments of stream condition**

4. How was the map developed?

The general method for developing the map is summarised in Figure 2, and the following sections provide a brief description of the key steps in the method. Appendix A provides a summary of the datasets used to develop the map.

The rationale for the method is consistent with fundamental approaches to natural resource management, where protecting ecosystems of high ecological value and good ecological integrity is more cost-effective than retrofitting restoration activities later in the process (Keenleyside et al. 2012).

Within the Wianamatta–South Creek catchment there are some waterways, riparian vegetation communities and water dependent ecosystems that are close to being in a reference or pristine state (see Blacktown City Council Waterway Health Report Card 2018–2019 (BCC 2019)). It is of particular significance however, that those in a degraded state still form important habitat corridors for many species including those that are critically endangered (H–N CMA 2007; DITRDC 2016, Sydney Water 2021a). Strategic planning priorities were therefore based on 2 planning goals, in which waterways, riparian corridors and other water dependent ecosystems are:

i. protected because of their high ecological value (biodiversity, habitat) and good ecological integrity or condition
ii. improved because they connect and help maintain the extent, cover and condition of the high ecological value waterways, riparian vegetation, and other water dependent ecosystems

4.1 Defining waterways and water dependent ecosystems

The waterways in the Wianamatta–South Creek catchment have been classified according to the Strahler stream classification system, which assigns each waterway an ‘order’ to reflect the number of tributaries associated with it. For example, headwater streams are assigned an order number of 1 whereas Wianamatta–South Creek itself is assigned an order number of 6 to indicate that 5 other tributaries flow into it.

The Strahler stream classification system is recognised in the *Water Management Act 2000* (WM Act) and *Fisheries Management Act 1994* (FM Act), as it provides a system for setting riparian corridor widths or identifying aquatic habitat values (see Section 4.2). Overall, there are 540 km of mapped 1st order streams in the Wianamatta–South Creek catchment, 290 km of 2nd order, 138 km of 3rd order, 114 km of 4th order, 12 km of 5th order and 62 km of 6th order streams. Of these, the 3rd order streams and above are generally identified as being perennial, and the remaining lower order identified as intermittent or ephemeral (Figure 3 and Figure 4).

In addition to the waterways, the Wianamatta–South Creek catchment is characterised by 3 other types of water dependent ecosystems, which we have classified in this study according to broad vegetation communities/groups. The riparian woodland vegetation community shown in Figure 3 covers a total area of over 30 km^2 in the Wianamatta–South Creek catchment. This community was considered distinct because of its dependence on waterways and shallow groundwater stores. The woody and non-woody wetland communities identified in Figure 4 are what are traditionally thought of as wetlands. They are vegetated, non-riverine or non-channel systems and include billabongs, swamps, bogs, springs and soaks. The non-woody wetland community also includes artificial wetlands such as farm dams. Overall, there are a total 13 km^2 of woody and non-woody wetlands that have been identified through a combination of existing mapping and satellite imagery (Appendices A, B).

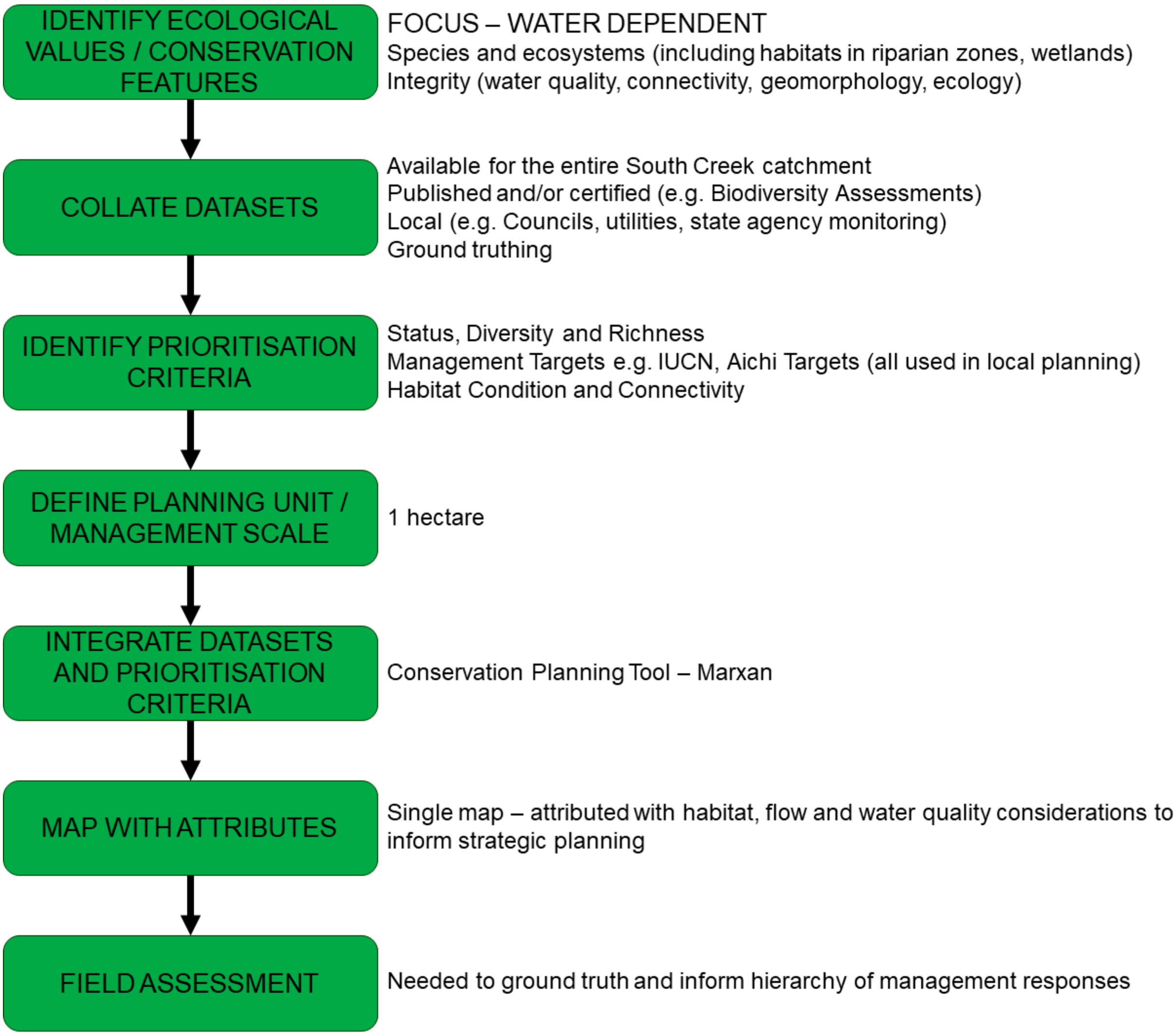

Figure 2 Overview of the method for developing a map of strategic planning priorities for protecting or improving the natural blue grid

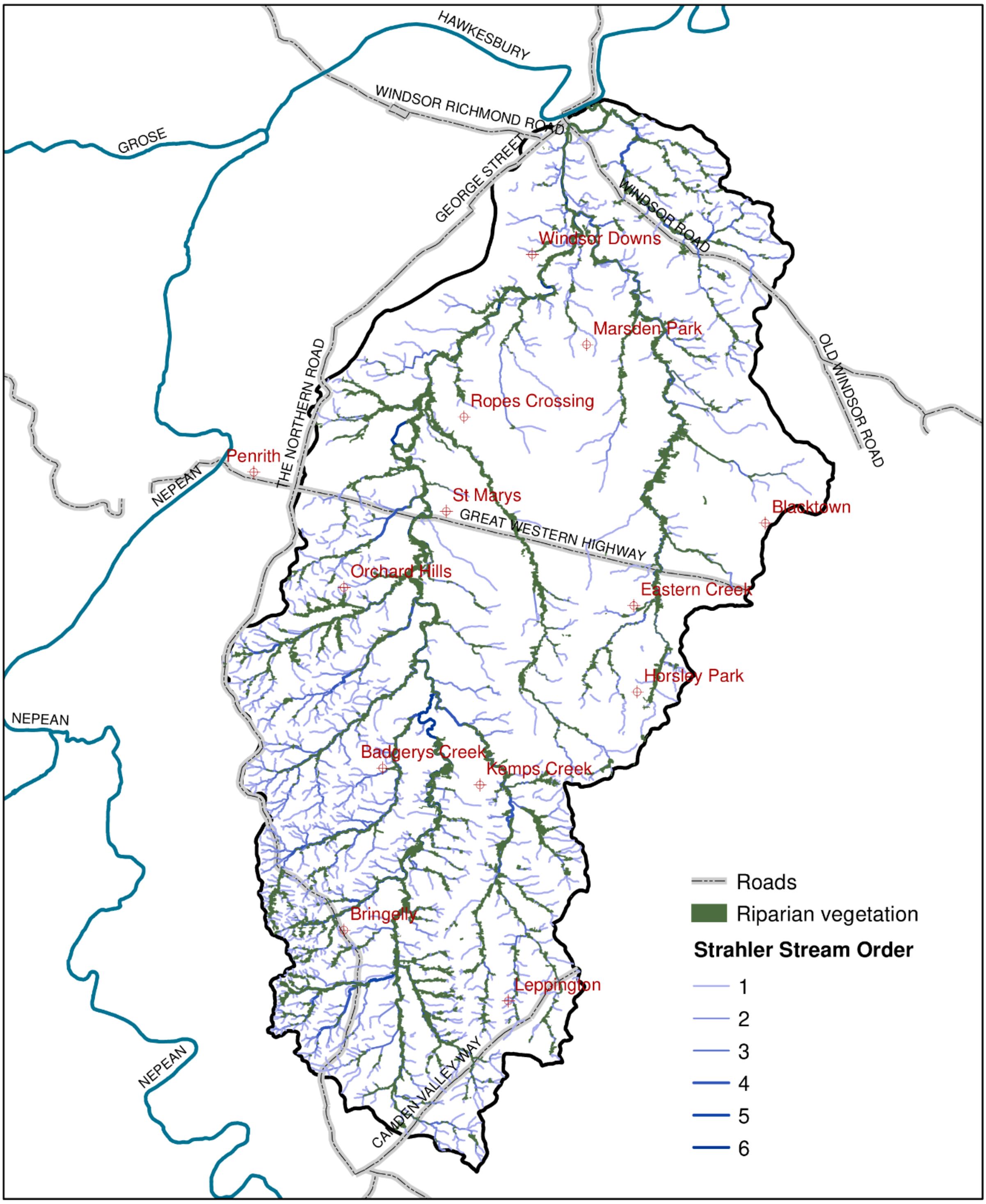

Figure 3 Waterways (Strahler stream order) and riparian vegetation in the Wianamatta–South Creek catchment

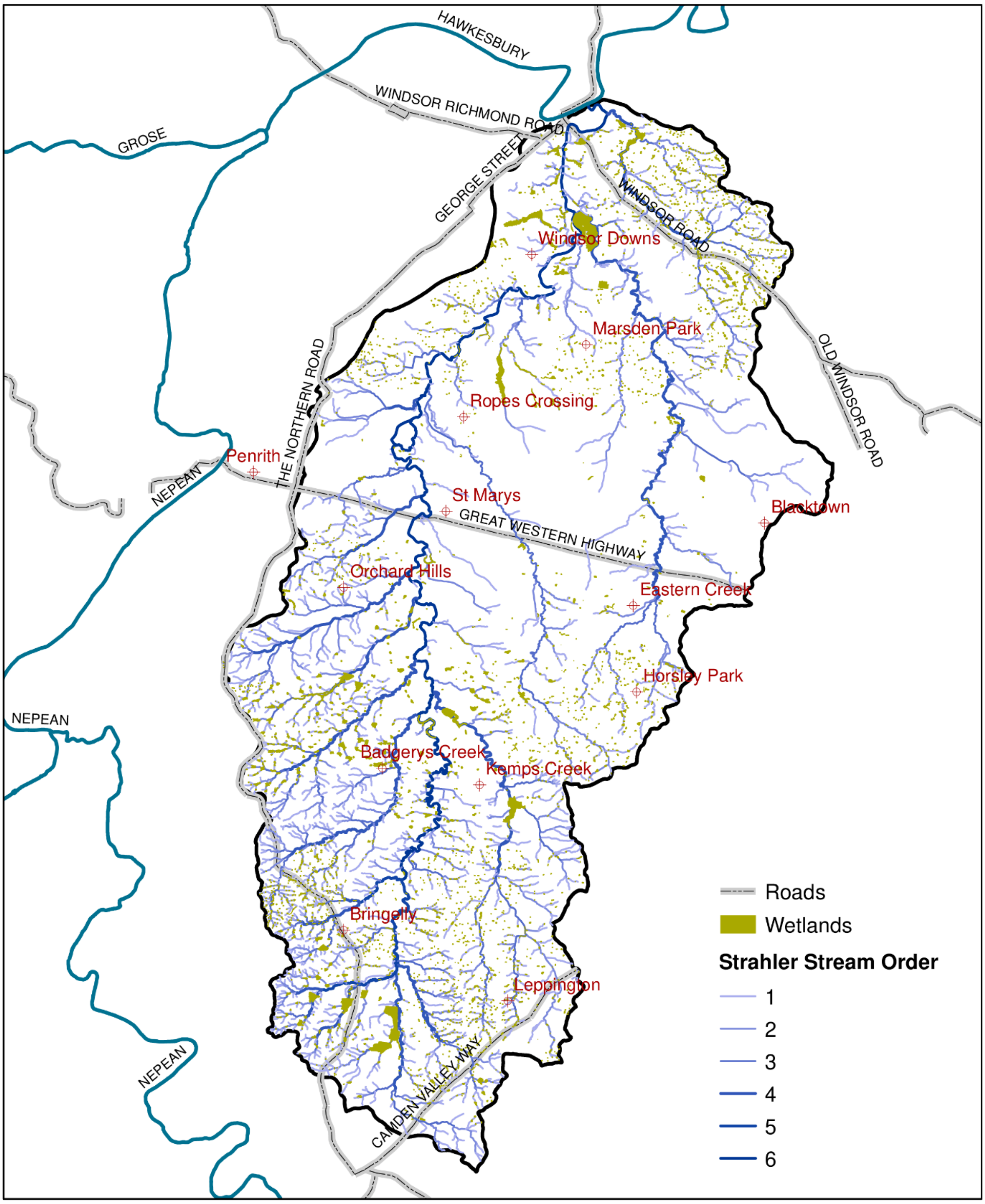

Figure 4 Waterways (Strahler stream order) and woody and non-woody wetlands in the Wianamatta–South Creek catchment

4.2 Defining high ecological values of the natural blue grid

Our definition for high ecological value waterways and water dependent ecosystems aligns with Commonwealth and state legislation, including the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), the *Biodiversity Conservation Act 2016* (BC Act), and the FM Act. These Acts provide schedules of endangered ecological communities and threatened species that require protection in the Wianamatta–South Creek catchment. The schedules were used as a starting point for defining the high ecological value waterways and water dependent ecosystems.

The BC Act also specifies a Biodiversity Information Program, to assess the management of biodiversity into the future and track progress towards achieving the main objects of the Act. A list of indicators for defining biodiversity and ecological integrity is available for terrestrial ecosystems (OEH and CSIRO 2019), with work underway to develop a list for freshwater ecosystems. The preliminary list for freshwater ecosystems includes riparian vegetation and water dependent species of frogs, birds, bats and reptiles. The extent and integrity of these preliminary indicators were mapped specifically for this study using habitat suitability models and remote sensing products (Appendix B). The list also includes macroinvertebrates, which are currently used to assess river health across the state. In this study, macroinvertebrate data were acquired to derive a biodiversity index.

To help implement the WM Act, the Department of Primary Industries – Water developed the NSW River Condition Index to quantify long-term river health and inform water allocations and catchment planning. The index includes a mapped waterway layer defining high ecological value aquatic ecosystems (HEVAE; Appendix A), which was used in this study to account for the requirements of the WM Act. The HEVAE have been defined according to 4 key criteria, which were determined by the Commonwealth: distinctiveness, diversity, naturalness and vital habitat. The index also relies on the River Styles Framework to map and identify river/stream types that need to be conserved because of their instream biodiversity value and good geomorphic condition.

The *Protection of the Environment Operations Act 1997* (POEO Act) is another piece of legislation relevant to this study because it requires industrial and wastewater discharges to be managed according to (protection and restoration of) the community environmental value and uses of waterways. These are what the community believes is important for a healthy ecosystem, for public benefit, welfare, safety or health. The community environment values and uses for Wianamatta–South Creek were determined in the late 1990s, as part of the Healthy Rivers Commission inquiry into the Hawkesbury–Nepean River system (Appendix A). These are currently being reviewed as part of the delivery of the Risk-based Framework under the MEMS and Aerotropolis Precinct Plan (DPE 2022a–d).

A summary of all blue elements/indicators to define high ecological value waterways, riparian vegetation communities and other water dependent ecosystems is provided in Table 1. The relevant legislation and policies that currently use the indicators are also provided in Table 1.

Table 1 Blue elements to define high ecological value waterways and water dependent ecosystems in Wianamatta–South Creek

Ecosystem	Description	Blue element	Legislation &/or policy
Terrestrial reserves	National Parks Wildlife Service and Crown land estate dedicated to conservation	Reserves	*National Parks and Wildlife Act 1974; Crown Lands Act 1989*
Waterways	Macroinvertebrate (biodiversity)	Shannon–Wiener index	WM Act
Waterways	River Biodiversity Condition Index	River Biodiversity Condition Index	WM Act
Waterways	HEVAE	HEVAE	WM Act
Waterways	Key fish habitat	Key fish habitat	Fisheries Policy – FM Act
Waterways	Fish nativeness of moderate or higher	Fish Nativeness	Fisheries Policy – FM Act
Waterways	Fish condition of moderate or higher	Fish condition	Fisheries Policy – FM Act
Waterways	4th order or greater streams	Strahler	BC Act
Waterways	Chain of ponds as per the River Styles assessment	River Styles	WM Act
Waterways	Geomorphic (good) condition as per the River Styles assessment	River Styles	WM Act
Waterways	Recovery potential of high or conservation as per the River Styles assessment	River Styles	WM Act
Waterways	Groundwater dependant ecosystems reliant on surface expression of groundwater	Groundwater dependent ecosystem	WM Act
Water dependent ecosystems	Coastal freshwater lagoons of the Sydney Basin Bioregion and South East Corner Bioregion	Endangered ecological community	BC Act
Water dependent ecosystems	Forest Red Gum – Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion	Endangered ecological community	BC Act
Water dependent ecosystems	Grey Myrtle dry rainforest of the Sydney Basin Bioregion and South East Corner Bioregion	Endangered ecological community	BC Act
Water dependent ecosystems	Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, Sydney Basin Bioregion	Endangered ecological community	BC Act
Water dependent ecosystems	Local Environment Plan riparian lands and watercourses	Riparian lands and watercourses	Standard Instrument Order 2006

Ecosystem	Description	Blue element	Legislation &/or policy
Water dependent ecosystems	Local environment plan environmentally sensitive areas	Riparian lands and watercourses	Standard Instrument Order 2006
Water dependent ecosystems	Environmental planning instrument - wetlands	EPI – wetlands	Standard Instrument Order 2006
Water dependent ecosystems	Riparian vegetation	Riparian vegetation	*BC Act; NSW Wetlands Policy*
Water dependent ecosystems	Wetlands, including farm dams	Wetland	*BC Act; NSW Wetlands Policy*
Water dependent ecosystems	Groundwater dependant ecosystems reliant on subsurface expression of groundwater	Groundwater dependent ecosystem	WM Act
Water dependent ecosystems	Frog sightings (threatened, critically endangered, vulnerable)	Threatened fauna sightings	BC Act
Water dependent ecosystems	Bird sightings (threatened, critically endangered, vulnerable)	Threatened fauna sightings	BC Act
Water dependent ecosystems	Bat sightings (threatened, critically endangered, vulnerable)	Threatened fauna sightings	BC Act
Water dependent ecosystems	Flora sightings (threatened, critically endangered, vulnerable)	Threated flora sightings	BC Act
Water dependent ecosystems	Important bird habitat	Community environmental value	*Used in various environmental legislation and planning policy
Water dependent ecosystems	Tree frog potential habitat	Community environmental value	*Used in various environmental legislation and planning policy
Water dependent ecosystems	Ground and burrowing frogs potential habitat	Community environmental value	*Used in various environmental legislation and planning policy
Water dependent ecosystems	Flying-fox potential habitat	Community environmental value	*Used in various environmental legislation and planning policy
Water dependent ecosystems	Microbats potential habitat	Community environmental value	*Used in various environmental legislation and planning policy

Ecosystem	Description	Blue element	Legislation &/or policy
Water dependent ecosystems	Southern myotis (fishing bat) potential habitat	Community environmental value	*Used in various environmental legislation and planning policy
Water dependent ecosystems	Emergent vegetation bird foragers potential habitat	Community environmental value	*Used in various environmental legislation and planning policy
Water dependent ecosystems	Large bird waders potential habitat	Community environmental value	*Used in various environmental legislation and planning policy
Water dependent ecosystems	Small bird waders potential habitat	Community environmental value	*Used in various environmental legislation and planning policy
Water dependent ecosystems	Open waterbird foragers potential habitat	Community environmental value	*Used in various environmental legislation and planning policy
Water dependent ecosystems	Riparian vegetation bird foragers potential habitat	Community environmental value	*Used in various environmental legislation and planning policy

* denotes community environmental values of ‘Protection of Aquatic Ecosystems’, which are described in the NSW Water Quality Objectives and are used in environmental legislation such as the POEO Act, and planning policies such as the Greater Sydney Region Plan – A Metropolis of Three Cities (GSC 2018).

4.3 Datasets

A range of existing spatial datasets (digital maps) and local field measurements were collated from state and local government agencies and utilities to inform/quantify the elements of the natural blue grid listed in Table 1. Some datasets were directly usable, while others required additional analysis such as spatial extrapolation to ensure the dataset represented the entire Wianamatta–South Creek catchment. A summary of all datasets and how they were used and analysed is provided in Appendix A.

4.4 Prioritisation criteria

The principles of systematic conservation planning (Margules and Pressey 2000) were used to prioritise which waterways, riparian vegetation communities and other water dependent ecosystems should be protected or improved. These principles ensure that protected areas are comprehensive, representative, adequate, efficient, flexible, irreplaceable and complementary. The first 3 principles are collectively known as the CAR principle, and have been adopted by the Commonwealth and all state and territory governments to define key criteria for developing national reserve systems (National Reserve System). The CAR principle has been used to identify priority conservation lands (for investment) in the Cumberland Plain, and is also reflected in a range of mandatory requirements for establishing biodiversity offsets under the BC Act (OEH 2018a). A general definition of the CAR principle, and the other related principles, is summarised in Kukkala and Moilanen (2013).

To operationalise the systematic conservation planning principles, a range of spatial prioritisation tools have been developed to assist decisions on areas for protection. Marxan is the most widely used tool for systematic conservation planning globally. It allows users to explicitly integrate many of the principles described above as criteria for prioritisation. Marxan was used to underpin the rezoning of the Great Barrier Reef Marine Park (Lewis et al. 2003) and has been used to inform management areas for water allocations of floodplains in the Murray–Darling Basin under the WM Act (e.g. DPIE 2020). Marxan was used in this study to create a single integrated map of strategic planning priorities for protection or improvement of the high ecological value waterways, riparian vegetation, and other water dependent ecosystems. Appendix C provides the details of how Marxan was used, including the scale of application, the criteria for prioritisation and additional datasets to account for the CAR principle. Of significance are numerical management targets, which are needed in Marxan to quantify the extent to which each blue element (listed in Table 1) should be protected. Past efforts to set targets for the Cumberland Plain have been fraught with difficulties due to competing land uses, high land values, high management costs and the continued threat of land clearing and fragmentation. A 15% conservation target for extant endangered ecological communities in the Cumberland Plain was in place prior to the BC Act (DECCW 2010b). This target has now been increased to 30% of the original (pre-1750) extents of endangered ecological communities to directly align with the targets recommended in the International Union for Conservation of Nature World Parks Congress (IUCN 2003; H–N CMA 2007; DECCW 2010b). Other targets currently in place for the Cumberland Plain include the Aichi Biodiversity Target 11, which recommends 17% of inland waterways be conserved, particularly those important for biodiversity and ecosystem services (OEH 2018a, b). A 100% conservation target for the rarest and most intact stream types has also been recommended to recognise the confinement of these stream types to the Cumberland Plain (H–N CMA 2007). Adoption of this latter target would help to ensure that prioritised areas for protection are representative.

Table 2 provides a summary of the management targets used in this study. The appropriateness of these specific targets for informing the South Creek Corridor Strategy and waterway objectives for Wianamatta–South Creek (to implement the Risk-based Framework required under the MEMS) was agreed in a stakeholder workshop attended by Infrastructure NSW, Sydney Water, the former Office of Environment Heritage, the NSW Environment Protection Authority and an independent reviewer with recognised expertise in defining the ecological values of waterways in the Wianamatta–South Creek catchment. The targets were also presented to the Department of Primary Industries – Fisheries in a separate workshop. In both workshops, the stakeholders were provided with 3 scenarios to demonstrate the sensitivity of outcomes to the management targets. All stakeholders agreed that the most pragmatic approach was to select the management targets shown in Table 2 since they align with targets being used to prioritise land investments under the Biodiversity Offsets Scheme of the BC Act.

Table 2 Management targets to quantify the extent of high ecological value waterways and water dependent ecosystems to protect in the Wianamatta–South Creek catchment

Ecosystem	Blue element	Management target*
Waterways	River Styles	100%
	Macroinvertebrates diversity	17%
	River Biodiversity Condition Index	17%
	Key fish habitats, and other fish measures	17%
	Strahler	17%
	HEVAE	17%
Water dependent ecosystems	Endangered ecological communities	30%
	Riparian vegetation	30%
	Woody and non-woody wetlands	30%
	Groundwater dependent ecosystems	17%
	Frog, bird, and bat habitats	17%
	Threatened species sightings	100%

* The management targets are specific to this study, to inform strategic planning priorities at the landscape scale and create a diagnostic map or tool (see Section 5). The targets should not be ubiquitously transferred/used in other studies without further consideration of existing policies and purpose of the study (i.e. are the targets fit for your purpose?).

4.5 Ground-truthing

A range of validation datasets were collected to assess the accuracy of the map. The datasets include field survey data, independent desktop analyses of sites, and the use of existing field survey datasets collated from the BioNet Vegetation Survey database, Blacktown City Council and the Conservation and Sustainability Branch of Department of Planning and Environment.

A total of 330 new field survey sites were assessed across the Wianamatta–South Creek catchment, specifically for this study, between March and August 2019 (Appendix D). The new field survey sites were combined with 66 field survey sites from previous studies, bringing the total number of validation sites to 396.

The accuracy assessment was based on the amount of agreement between the validation datasets and the mapped values (Stehman and Czaplewski 1998). The results are expressed as overall accuracy (number of agreements) and kappa statistics, which quantifies the agreement due to chance. In addition, confusion matrices were used to identify the sources of error.

The results show that the map has an overall accuracy of greater than 80%, which is typically deemed acceptable for maps to support natural resource planning (Stehman and Czaplewski 1998). The accuracy of the individual datasets varied, with some showing greater agreement with the validation datasets than others. In general, the validation datasets showed a greater number and extent of indicators than is currently mapped (i.e. greater ecological value).

5. What does the map show?

The map shown in Figure 5 brings together datasets used by the Commonwealth, state and local governments to implement various legislation and policies for managing waterways and (water) biodiversity in NSW (Appendices E, F). It should not replace the intent of the original (finer-scale) datasets or mapping but rather be used as a diagnostic tool to identify strategic planning priorities, as has been done in this study and in the applications described below.

The map consists of 2 planning goals that can be aligned with the objectives of the Environment and Recreation Zone of the *State Environmental Planning Policy (Precincts – Western Parkland City) 2021*.

The planning goal identified as 'protect' aligns with zone objectives to:

- protect, manage and restore areas of high ecological, scientific, cultural or aesthetic values
- protect and conserve the environment, including threatened and other species of native fauna and flora and their habitats, areas of high biodiversity significance and ecological communities.

The planning goal identified as 'improve' aligns with zone objectives to:

- protect the ecological, scenic and recreation values of waterways, including Wianamatta–South Creek and its tributaries
- provide a range of recreational settings and activities and compatible land uses.

The map identifies a total of 102 km^2 of 'protect' areas, of which 12.5% lie within the established reserves and parks of the Wianamatta–South Creek catchment and 23% in areas of Existing Native Vegetation (ENV) designated to be protected (on non-certified land) in accordance with the Order to confer biodiversity certification under the State Environmental Planning Policy (Sydney Region Growth Centres) 2006. The remaining 64.5% of protect areas are located around large stands of remnant Cumberland Plain vegetation (River-Flat Eucalypt Forest on the Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions) that are water dependent.

Figure 6 provides a series of photographs showing the natural character of the 'protect' areas. Figure 6a was taken from the Little Creek tributary, which is located within a predominantly naturally vegetated catchment. The structure of the riparian vegetation is intact with obvious ground cover, mid-story and canopy cover sections. The vegetation buffer is extensive and dominated by native grassland. The surrounding native trees are classed as groundwater dependent ecosystems. Figure 6b was taken at South Creek above the Richmond Road bridge. It is characteristic of a highly sensitive key fish habitat (Type 1), that contains instream gravel beds, rocks greater than 500 mm in 2 dimensions, snags greater than 300 mm in diameter or 3 m in length and the presence of native aquatic plants. Figure 6c depicts a remnant *Eucalyptus tereticornis* that has developed hollows. The hollows are essential habitat for a variety of birds and mammals in the catchment. Figure 6d shows a small wetland branching off from Badgerys Creek. The wetland has an abundance of native macrophytes and riparian vegetation. Entry to the wetland is shallow, falling to a maximum depth of approximately 30 cm in the centre. These characterises are conducive to supporting a diverse frog community.

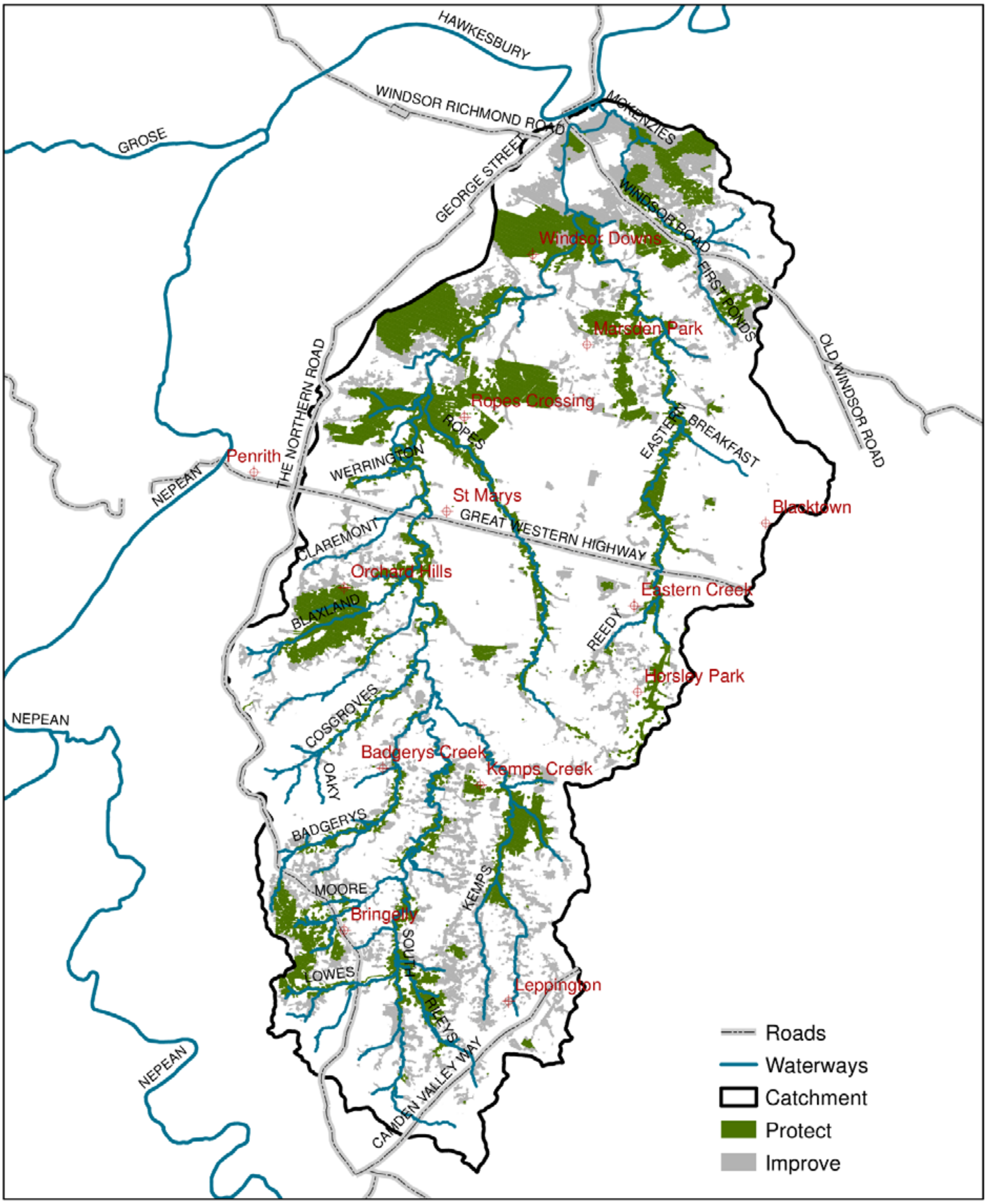

Figure 5 Strategic planning priorities for protecting or improving the natural blue grid in the Wianamatta–South Creek catchment

The ‘improve’ areas also include important habitats, but not to the same extent, and are in poorer condition. Figure 7a represents a reach in an altered state/relatively poorer condition, however there are significant opportunities for ecological improvement. The biodiversity is low with vegetation consisting mainly of pasture grasses with a narrow fringe of *Casuarina glauca*. However, due to the wide riparian buffer (>500 m), there is an opportunity to revegetate to improve the ecological condition of the reach and provide habitat through nest boxes that mimic natural hollows. Under the key fish habitat classification, the reach shown in the photograph is classed as Type 3, Class 3 with low/sporadic flows and low instream habitat complexity. Field measurements, however, show a good potential for improvement through enhancement of the existing overhanging vegetation and instream woody debris.

Areas that have not been attributed with a planning priority of ‘protect’ or ‘improve’ are those in the most degraded state (Figure 7b). These areas have low vegetation coverage, usually dominated by invasive species. The areas are typically susceptible to illegal dumping and can have a high volume of litter. Owing to their disturbed state, these areas have low habitat value and support limited biodiversity. Streams in these areas are degraded, with poor water quality and altered hydrology. Accordingly, key fish habitat scores are typically low, indicating streams are unlikely to support diverse aquatic life.

Figure 6 Characteristic features of waterways and water dependent ecosystems in the ‘protect’ areas of the map of the natural blue grid

a) improve

b) degraded

Figure 7 Characteristic features of waterways and water dependent ecosystems in the 'improve' areas of the map of the natural blue grid or in areas that have not been recognised in the map due their degraded state

6. How has the map been used?

As an urban parkland, the South Creek Corridor Strategy was designed to respond to its climatic and landscape settings, with areas of higher density and high-quality public spaces orientated towards (cooler) waterways. The map was used to inform the key environmental indicators and associated extent of beneficial costs for the economic appraisal of the Infrastructure NSW Strategic Options Business Case for the South Creek Corridor Strategy (INSW 2019). The net benefits of protecting and improving the natural blue grid were estimated to be over $1 billion and include benefits for communities both within the South Creek Corridor (e.g. bass fishing) and downstream in the Nepean River and out towards the ocean (see also Bennett et al. 2015). Since this work, the map has been used to inform the Western Sydney Place Infrastructure Compact (GSC 2020a), Aerotropolis Precinct Plan (WSPP 2020; Sydney Water 2021a, b), priorities for the place-based delivery strategy for the Wianamatta South Creek precinct (DPIE 2021a), and the Liverpool City Council vegetation strategy for riparian lands (CTENVIRONMENTAL 2020). The following sections provide an overview of the first 2 of these applications.

6.1 Western Sydney Place Infrastructure Compact

A Place Infrastructure Compact (PIC) is a new model, developed by the Greater Sydney Commission, to identify the most effective way of sequencing infrastructure for urban growth over time. The model is evidence and outcomes focused and looks at a place holistically by identifying both city building infrastructure such as roads, public transport and water services, and city making infrastructure underpinned by environmental and social needs.

The PIC for Western Sydney considered up to 28 precincts within the Aerotropolis and Greater Penrith and Eastern Creek urban growth areas. The map was used to identify, locate and cost natural blue infrastructure projects, specifically for waterway management (≥2nd order streams) and revegetation of riparian corridors as required under the NSW Office of Water specifications for vegetated riparian zones (DPI – Office of Water 2012). The costs for the ‘protect’ areas were lower than costs for ‘improve’ areas, on the assumption that ‘protect’ areas are in relatively good condition (integrity) and therefore only need to be enhanced through revegetation and weeding. Costs for ‘improve’ areas included stabilisation of stream banks, through both revegetation and armouring. Costs were assigned to all extant waterways and riparian corridors, and hence, represented the largest proportion (37.5%) of the total land area required for infrastructure within the PIC. However, the total cost of the natural blue infrastructure projects was only 16.4% of all capital costs, with unit costs relatively lower than those for city building infrastructure.

The individual blue elements making up the map were used as the basis for monitoring against the Greater Sydney Commission’s place outcome ‘Scenic productive and resilient landscapes: a city in its landscape’. For example, a metric to monitor the benefits of investments for enhancing extant water dependent vegetation through revegetation and weeding was based on field assessments of vegetation integrity, following the requirements under the Biodiversity Assessment Method (OEH 2018b). The baseline assessment for this metric indicated that the proportion of water dependent vegetation in the PIC area in excellent condition is 18.4%, in good condition 11.3%, fair condition 21.3%, poor condition 31.3%, and very poor condition 17.8%. For waterways, the baseline assessment indicated that the water quality at representative sites was predominantly (98%) poor. Note that these metrics are directly related to the extent of impermeable (i.e. hard) surfaces, which has been used by the Greater Sydney Commission as a measure for ‘water in the landscape’ and reducing urban heat (see GSC 2020b; Chirgwin and Dela-Cruz 2022).

6.2 Aerotropolis Precinct Plan – Riparian Corridors Assessment and Stormwater and Water Cycle Management

Requirements for protecting and restoring waterways and riparian vegetation are identified in almost all planning elements of the Aerotropolis Precinct Plan, from Aboriginal heritage and the Blue and Green Infrastructure Framework to tree canopy cover, linear parks and urban typologies. The Western Sydney Aerotropolis (Initial Precincts) Riparian Corridors Assessment (WSARCA; Sydney Water 2021a) effectively operationalises the waterway management and riparian corridor revegetation projects identified in the Western Sydney PIC. The WSARCA used the 'protect' and 'improve' areas of our map to develop guiding principles for identifying the specific waterways and associated riparian corridors that will be retained in the priority precincts of the Aerotropolis. The principles have been adopted in the development control plan for the Aerotropolis, as a performance outcome for developments to retain and restore native vegetation and riparian corridors (DPIE 2021b).

Similar to the Western Sydney PIC, the WSARCA has used the 'protect' and 'improve' areas of the adapted map to assign indicative costs for revegetation, weed control and bank stabilisation of waterways. Assumptions for costings in the Western Sydney PIC were validated in the WSARCA using the field survey data collected in this study (Appendix D). This validation confirmed that 'protect' areas had relatively greater native vegetation extent and lower weed cover compared to the 'improve' areas. Under the WSARCA, it was further assumed that waterways and riparian corridors outside of the 'protect' and 'improve' areas were of poorest condition and likely to require greater capital input to improve.

The map has also guided the locations of wetlands, stormwater detention basins and water sensitive urban design in the Aerotropolis (Sydney Water 2021b). This infrastructure has been placed mostly around the periphery of the map, so as to work as closely as possible with the landscape but providing enough storage of stormwater to minimise changes to the stream hydrology and minimise streambank and bed erosion.

6.3 Aerotropolis Precinct Plan – performance outcomes for protecting and improving the natural blue grid and managing stormwater

Performance outcomes for protecting and restoring the natural blue grid and managing stormwater in the Aerotropolis are described in a companion study (DPE 2022a). They were based on the habitat, water quality and flow related requirements of the individual blue elements making up the map and were essentially used as a benchmark for new stormwater quality and quantity controls in both the Aerotropolis Development Control Plan and Mamre Rd Precinct Development Control Plan. The stormwater quality load reduction targets and stormwater quantity/volumetric flow targets in these development control plans directly achieve the performance criteria. Table 3 provides an example for one blue element of the map, which was used to represent the high ecological value of fish in the Wianamatta–South Creek catchment. In this example, the presence of key fish habitat 'switched on' requirements under the FM Act, and the NSW Department of Primary Industry – Fisheries *Policy and guidelines for fish conservation and management* (DPI – Fisheries 2013). Three types of key fish habitats have been defined in NSW depending on their sensitivity to land-use activities, including urban development. The field surveys, which were undertaken to ground truth the map, showed that all 3 types of key fish habitat are present in the Wianamatta–South Creek catchment (Appendix E). The dominant combination of key fish habitat in the Aerotropolis is Type 2 Class 2, and as shown in Table 3, existing policy and guidelines can then be used to inform the type of habitat restoration and the extent of stormwater quantity and quality required to protect this specific ecological value.

The 'classification for fish passage' can be used to inform the timing and duration of stormwater discharges from development sites in the Aerotropolis (DPE 2022a–d). Similarly, the water quality requirements of fish can be used to inform the quality of stormwater discharges from development sites. Generally, the NSW Department of Primary Industry – Fisheries requires no net impact of land-based pollutants on key fish habitats, and as a default, specify ambient concentrations of nutrients, sediments and other water quality parameters described in the Australia and New Zealand Environment Conservation Council Guidelines for Fresh and Marine Water Quality (ANZECC and ARMCANZ 2000).

Table 3 Basis for water quality and flow related objectives for protecting key fish habitat in the Aerotropolis – adapted from DPI – Fisheries 2013

Blue element	Type and sensitivity classification	Classification for fish passage	Water quality
Key fish habitat	Type 1 – highly sensitive Type 2 – moderately sensitive Type 3 – minimally sensitive e.g. Type 2, relevant to Wianamatta Freshwater habitats and brackish wetlands, lakes and lagoons other than those defined in Type 1, and weir pools and dams up to full supply level where the weir or dam is across a natural waterway.	Class 1 – major Class 2 – moderate Class 3 – minimal Class 4 – unlikely e.g. Class 2 Non-permanently flowing (intermittent) stream, creek or waterway (generally named) with clearly defined bed and banks with semi-permanent to permanent waters in pools or in connected wetland areas. Freshwater aquatic vegetation is present. Type 1 and 2 habitats present.	Nutrients, dissolved oxygen, pH, turbidity, temperature, salinity chemical contaminants – as required for breeding, feeding and maintaining quality of habitat. Default is Australian and New Zealand Guidelines for Fresh and Marine Water Quality 2000 (ANZECC guidelines)

6.4 Strategic alignment with the Greener Places Design Guide

The planning goals outlined in this study to 'protect' or 'improve' waterways and water dependent ecosystems support the design principles of the NSW Government Architect's draft Greener Places Design Guide. This guide provides principles for designing urban ecosystems and explicitly recognises the role of waterways in shaping our urban environment and supporting natural biodiversity. The 'protect' areas in our map of the natural blue grid in Wianamatta–South Creek directly align with the 'protect and enhance' strategy of the draft Greener Places Design Guide. This strategy specifies that the design process should start with protecting what's already there, specifically enhancing and restoring the health of the existing remnant ecosystems to prevent further habitat and biodiversity loss. The 'improve' areas in our map of the natural blue grid directly align with the 'improve and create' strategy of the guide. This strategy specifies that the design process should improve areas to a new urban condition where the area cannot be restored, and create habitat linkages within a riparian corridor to support connectivity.

An example of how the 'protect' and 'improve' areas of the map have been used to design the indicative layout plan for the Aerotropolis Core Precinct in the Aerotropolis is shown at Appendix C, Figure 11.

7. Natural blue grid mapping for Greater Sydney

As a result of this study, the Environment and Heritage Group of Department of Planning and Environment has developed a new series of natural blue grid maps for each local government area in the Greater Sydney Region and for the Wilton and Greater Macarthur Growth Areas located south of the Wianamatta–South Creek catchment (Dela-Cruz et al. 2022). This series of maps was designed to support delivery of Strategies 25.1 and 25.4 of the Greater Sydney Region Plan (GSC 2018), which are to protect environmentally sensitive waterways and the coastal environment, and reinstate more natural conditions in highly modified urban waterways, respectively.

Similar to what was produced in this study, this new series of natural blue grid maps brings together the blue elements (indicators) that are recognised as high ecological value in each area. The new series of maps do not identify 'protect' and 'improve' areas, because these need to be delineated through specific criteria relevant to the area and to the intended use of the map; however, the series includes a map attribute titled 'TVALUE' to help with priority setting. The TVALUE was developed as a relative heuristic measure of the ecological value of an area. It simply represents the total number (value) of blue elements present within a 1 ha planning grid, with the assumption that the greater the TVALUE the greater the number of blue elements present and hence greater ecological value of the area. Examples of how this new series of map can be used in strategic planning are available in the Land Use and Infrastructure Implementation Plan for Wilton and Greater Macarthur (DPE 2018a, b), the Macquarie Park Place Strategy and accompanying Strategic Infrastructure and Service Assessment (DPIE 2021c; GSC 2021), and the Northern Beaches Council Local Strategic Planning Statement (NBC 2020).

7.1 Access the maps from SEED

SEED is the NSW Government's central resource for *S*haring and *E*nabling *E*nvironmental *D*ata. It was developed for the NSW community in a collaborative effort between government agencies to provide an accessible and reliable platform for environmental data.

In SEED, we have released:

- natural blue grid for the Wianamatta–South Creek, which includes the protect and improve areas as shown in Figure 5
- new series of natural blue grid mapping for the Greater Sydney Region (High Ecological Value Waterways and Water Dependent Ecosystems – Greater Sydney Region).

In all cases, the maps are provided as shapefiles and are accompanied by a table summarising the blue elements (or indicators) that make up the map.

8. Acknowledgments

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10. More information

- About BioNet Vegetation Classification
- Aquatic Ecosystems Toolkit
- Atlas of Living Australia
- AUSRIVAS
- Biodiversity Conservation Act 2016
- BioNet Atlas search
- BioNet Systematic Flora Survey data collection
- BioNet Vegetation Classification
- BioNet Vegetation Survey database
- Blacktown City Council Waterway health report card 2018–2019 (PDF 4.7MB)
- Bureau of Meteorology Climate Data Online
- Castlereagh Swamp Woodland Community profile
- Condition of fish communities in NSW
- Copernicus Open Access Hub
- Cost Distance Tool in ArcGIS 10.4
- Crown land in NSW maps
- Determining stream order fact sheet (PDF 93KB)
- Digital Elevation Model (DEM) of Australia derived from LiDAR 5 Metre Grid
- Ecological carrying capacity of terrestrial habitat dataset
- Environmental planning instrument – environmentally sensitive land
- Environmental planning instrument – riparian lands and watercourses
- Environmental planning instrument – wetlands
- Environment Protection and Biodiversity Conservation Act 1999
- Freshwater Wetlands on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions profile
- Greater Sydney Commission's Region Plan (A Metropolis of Three Cities)
- Groundwater dependent ecosystems

- High Ecological Value Waterways and Water Dependent Ecosystems – Greater Sydney Region
- High Ecological Value Waterways and Water Dependent Ecosystems in Wianamatta–South Creek
- Interpretation Guidelines for the Native Vegetation Maps of the Cumberland Plain, Western Sydney (PDF 1.1MB)
- Important bird areas
- Key fish habitat maps
- Land and Property Information topographic map 2012
- Land and Soil Capability Mapping for NSW
- Marine Estate Management Strategy 2018–2028
- Marxan software
- National Reserve System
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- River Condition Index
- River-Flat Eucalypt Forest on Coastal Floodplains of the NSW North Coast, Sydney Basin and South East Corner Bioregions profile
- River Styles
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- RivEX tool
- SEED
- Southeast NSW Native Vegetation Classification and Mapping – SCIVI (VIS_ID 2230)
- Sydney Urban Bushland Biodiversity (Pre-European) 1997 VIS_ID 4104
- Threatened species & ecological communities

Appendix A – Datasets

This appendix provides a summary of key datasets considered and/or used in the creation of the single thematic map of high ecological value waterways and water dependent ecosystems (viz. natural blue grid). The first section (Section A.1) summarises datasets for waterways, the second section (Section A.2) datasets for water dependent ecosystems, and the last section (Section A.3) datasets for identifying strategic planning priorities in Marxan.

Some datasets were not explicitly included in this study because their intent was captured in other datasets that were used directly. Specifically, the datasets for Commonwealth listed critically endangered ecological communities and Species of National Significance were not included because the communities and species were captured in certified datasets (used in the BC Act) on endangered ecological communities and threatened species sightings in NSW. Datasets (mapping) contained in local environmental plans showing environmentally sensitive areas, wetlands, riparian lands, watercourses, wildlife corridors or high ecological value areas were captured by the respective vegetation and wetland datasets used directly in this study.

Note that maps of the datasets, which were used for the Marxan analysis, are provided separately in Appendix E. The maps are cross-referenced from the respective sections below.

A.1 Datasets for waterways

Macroinvertebrates

Macroinvertebrate data were sourced directly from the Environment, Energy and Science Group of Department of Planning and Environment and councils within the Wianamatta–South Creek catchment. Raw data were scored against the Australian River Assessment System on the health of freshwater ecosystems – AUSRIVAS. AUSRIVAS was developed under the National River Health Program (NRHP) funded by the Commonwealth Government in 1994, in response to growing concern in Australia for maintaining the ecological values of our rivers. AUSRIVAS has 2 streams, biological and physical assessment. These correspond with the biological assessment protocols and the geomorphic, physical and chemical assessment protocols, respectively.

River Biodiversity Condition Index

The River Condition Index (Appendix E, Figure 12) is the primary long-term reporting tool for assessing change in riverine condition. The index is used in State of the Environment reporting.

The index was developed using the Framework Assessment of River and Wetland Health (FARWH) approach. This approach is based on a hierarchical model of river function. The FARWH recognises the effects of catchment disturbance, physical form of the landscape, hydrologic regime, water quality, fringing zone and aquatic biota as measures of river health. The FARWH method uses existing data collection activities across Australia. It converts them into a standardised and nationally comparable representation of river health.

A component of the River Condition Index is the River Biodiversity Condition Index, which is calculated using the Aquatic Biodiversity Forecaster Tool (Turak et al. 2011) and based on macroinvertebrates assemblages. Macroinvertebrates are used as a surrogate measure of instream biota and many taxa have been shown to be responsive to broad-scale landscape attributes alteration to natural flow regimes and water quality.

Shannon–Wiener diversity index

In addition to the River Biodiversity Condition Index, we calculated the Shannon–Wiener diversity index (Appendix E, Figure 13) from the local field collections of the (raw) abundance of species of macroinvertebrate using Primer Version 7.1. The resulting Shannon–Wiener diversity indices at the field sites were then extrapolated to all 3rd order streams using the spatial statistical modelling technique described in Appendix B. This approach produced a data layer that more closely reflected the spatial trends in the local field data.

High ecological value aquatic ecosystems

The Aquatic Ecosystems Toolkit is a nationally agreed framework that provides a set of good practice tools for mapping, classifying and assessing the condition of aquatic ecosystems, and provides guidance to identify high ecological value aquatic ecosystems – HEVAE (Appendix E, Figure 14). The toolkit has been developed to complement existing assessment tools and is flexible in its application. It includes 5 modules: Aquatic Ecosystems Toolkit Guidance Paper, Interim Australian National Aquatic Ecosystems (ANAE) Classification Framework, Guidelines for Identifying High Ecological Value Aquatic Ecosystems (HEVAE), Aquatic Ecosystem Delineation and Description Guidelines, and an Integrated Ecological Condition Assessment Framework (IECA). The toolkit was used to develop the HEVAE subindex in the NSW River Condition Index spatial data layer, which was sourced directly from the NSW Department of Primary Industries – Fisheries.

Key fish habitat

Key fish habitat includes all marine and estuarine habitats up to highest astronomical tide level (that reached by 'king' tides) and most permanent and semi-permanent freshwater habitats including rivers, creeks, lakes, lagoons, billabongs, weir pools and impoundments up to the top of the bank (Appendix E, Figure 15). Small headwater creeks and gullies (known as 1st and 2nd order streams), that only flow for a short period after rain are generally excluded, as are farm dams constructed on such systems. Wholly artificial waterbodies such as irrigation channels, urban drains and ponds, salt and evaporation ponds are also excluded except where they are known to support populations of threatened fish or invertebrates. Maps were compiled on the basis of local government areas and were sourced directly from the NSW Department of Primary Industries – Fisheries.

Fish condition and nativeness

The condition of fish communities in NSW is derived from the 3 condition indicators of expectedness, nativeness and recruitment, built from a number of field datasets owned by the NSW Department of Primary Industries – Fisheries. The field datasets include measures of the abundance, population and diversity of fish at any one sampling site.

The indicators and the overall fish condition metric have been produced from sampled reaches using a suite of environmental variables extracted from the National Hydrological Geospatial Fabric Version 2 environmental attribute tables (NHGFV 2).

Outcomes rate the condition of fish communities as very good, good, moderate, poor or very poor. The condition and nativeness of fish communities (Appendix E, Figure 16 and Figure 17, respectively) rated as moderate or higher were used as an input to Marxan in this study to the develop the single thematic map of high ecological value waterways and water dependent ecosystems (viz. natural blue grid).

Strahler stream order

The RivEX tool was used to generate a statewide layer of Strahler stream order (Appendix E, Figure 18) using the 2012 Land and Property Information topographic map. RivEX implements a fast-recursive algorithm to calculate Strahler stream order, stream segments and can deal with multi-channelled networks.

The Strahler system is based on the confluence (joining) of streams of the same order. A 1st order stream has no other streams flowing into it. When 2 streams with different orders join, the resulting stream has the same order as the highest order of the 2 joining streams. For example, when a 1st and 2nd order stream join, the resulting stream is 2nd order. When 2 streams with the same order join, the resulting stream has the next highest order than the joining streams. For example, when two 2nd order streams join, the resulting stream is 3rd order. A stream may separate and then converge – this is called a 'braided stream'. A braided stream retains the same stream order throughout the braid, as though it were a single stream. A lake may be located on a stream. The occurrence of a lake does not change the stream order of a stream. Further information is available in the *Determining stream order* fact sheet.

River Styles (chain of ponds, geomorphic condition, recovery potential)

The River Styles Framework is an approach to the geomorphic analysis of river systems, developed at Macquarie University. Use of all 4 stages of the framework provides coherent, scaffolded baseline information for use in river management. Stage 1 is used to identify river types (Styles, e.g. *chain of ponds*) and interpret their forms, processes, behaviour, patterns in catchments and controls on their character and behaviour (Appendix E, Figure 19). Stage 2 is used to interpret *geomorphic condition* in the context of river evolution (Appendix E, Figure 20). The data can be used to describe the extent to which the river has been altered relative to an expected reference condition and to identify causes of deterioration or improvement. Stage 3 places each reach within its catchment context to analyse river *recovery potential*, based on the connectivity of reaches within that catchment (Appendix E, Figure 21). The data can be used to identify trajectories of geomorphic recovery and likely timeframes for recovery. Stage 4 provides an approach to vision-setting and conservation first and recovery-based prioritisation for river management.

Groundwater dependent ecosystems, reliant on surface expression of groundwater

This dataset expresses the potential for groundwater interaction/use for river/spring/wetland ecosystems across Australia (Appendix E, Figure 22). It shows the ecosystems that rely on groundwater that has been discharged to the surface, such as baseflow or spring flow. The dataset was created by analysing all river/spring/wetland polygons contained in existing maps, and the outcome of the analysis identified which of those polygons were potentially interacting with groundwater. All river/spring/wetland polygons are considered to be accessing a source of water in addition to rainfall, and hence, they are all inflow dependent ecosystems (IDEs). The river/spring/wetland ecosystems were analysed to determine whether the additional water source was likely to be groundwater, water in the unsaturated zone or surface water. Where this additional information enabled a conclusion to be made on the potential of each river/spring/wetland ecosystem to be interacting with groundwater, the ecosystem was included in the GDE layer ('Reliant on surface expression of groundwater') and categorised as having either a high, moderate or low potential for groundwater interaction.

Community environmental values and uses of waterways

Spatial datasets identifying the environmental values of the waterways in South Creek were obtained from the Healthy Rivers Commission report for the Hawkesbury–Nepean River system. The report shows there are 8 environmental values designated to the waterways in the South Creek catchment depending on the surrounding catchment land use. Those that apply to all waterways include protection of aquatic ecosystems, secondary contact recreation, and visual amenity. In this study, we focused on protection of aquatic ecosystems, on the assumption that this environmental value will remain a community expectation into the future as the South Creek catchment is urbanised. This assumption is reflected in the visions for the Western Parkland City and in recent community surveys conducted by the Environment Energy and Science Group of Department of Planning and Environment (DPE 2022). The ANZECC and ARMCANZ (2000) guidelines indicate that protection of aquatic ecosystems requires 'maintaining or improving the ecological condition of water bodies and their riparian zones', and that protecting aquatic ecosystems also protects the other environmental values and uses. Typically, the NSW Environment Protection Authority relies on water quality data to determine if the protection of aquatic ecosystems is being achieved in the waterway before setting point source (industrial) discharge limits.

Water quality

For this study, we collated all available water quality datasets from state and local government monitoring programs and from Sydney Water, who is required to monitor water quality for its environment protection licences. Datasets were mostly available for waterways on the eastern side of the catchment. To provide an objective representation of water quality across the South Creek catchment, we extrapolated the field observations to all 3rd order (perennial) streams via a spatial statistical modelling technique developed by researchers at the Commonwealth Scientific Industrial Research Organisation (CSIRO) and the United States National Oceanic and Atmospheric Administration (Appendix B, Section B.4). This modelling technique is specific to stream networks because the models account for patterns of spatial autocorrelation among locations (see Appendix B).

A.2 Datasets for water dependent ecosystems

Environment Protection and Biodiversity Conservation Act 1999 listed threatened species and ecological communities and list of NSW endangered ecological communities

The EPBC Act provides for the listing of nationally threatened native species and ecological communities, native migratory species and marine species. The lists are provided on the website of the Act, and spatial data layers showing endangered ecological communities or known occurrences of listed ecological communities (Appendix E, Figure 23) were obtained from the Environment, Energy and Science Group of Department of Planning and Environment, as listed under the BC Act.

Environmental planning instrument – riparian lands and watercourses

This spatial dataset identifies land where development implications exist to reduce impacts in riparian lands and watercourses, as designated by a NSW environmental planning instrument. Riparian lands are a transition zone between the land and a watercourse that is important for maintaining or improving its shape, stability and ecological functions.

Environmental planning instrument – environmentally sensitive land

This spatial dataset identifies environmentally sensitive lands that are subject to 'Additional Local Provisions' found in Part 6 (or Part 7) of the local environmental plan. Local provisions help to augment existing zoning to ensure special environmental features are considered.

Environmental planning instrument – wetlands

This spatial dataset identifies land where development implications exist due to the presence of wetlands, as designated by the relevant NSW environmental planning instrument. The NSW Wetlands Policy promotes the sustainable conservation, management and use of the state's wetlands.

Riparian vegetation and wetlands (including farm dams)

The remnant riparian vegetation and wetland datasets (see Figure 3 and Figure 4) were developed by initially combining 3 spatial datasets using a hierarchy of decision rules and then checking against 2017–18 aerial imagery (see NSW_Imagery (MapServer)) to account for any unmapped wetlands. The input datasets included:

- The revised 'Remnant Vegetation of the western Cumberland subregion, 2013 Update VIS 4207' dataset provides detailed information on the native vegetation communities, including a fine level of floristic classification detail for plant communities. The dataset was checked against (and where appropriate mapped extents updated) the most up-to-date aerial imagery (James 2018). The dataset does not identify areas of open water (otherwise known as non-vegetated wetlands).
- Native Vegetation of the Sydney Metropolitan Area – Version 3.1 (OEH 2016) VIS_ID 4489. This dataset is part of the NSW State Vegetation Type Map, and provides a fine level of linework (delineation of polygon boundaries) and is more up-to-date with respect to clearing and regrowth of native vegetation extent. However, at the time of this study, the dataset only described broad structural vegetation classes.
- NSW Hydro Area Dataset.

A summary of methods for developing the datasets is provided in Appendix B. Note that the final step in developing the datasets involved manually reconciling against 2017–18 aerial imagery and satellite imagery to account for recent clearing of vegetation and urban development. The satellite imagery was based on the Sentinel-2 satellite imagery (10 m true colour) with an image observation date of 31/01/2018. The image was downloaded from the Copernicus Open Access Hub. The final dataset is identified as Riparian vegetation and wetlands of the South Creek Catchment, Western Sydney (2018).

Groundwater dependent ecosystems, reliant on sub-surface expression of groundwater

This dataset expresses the potential for groundwater interaction/use of vegetation ecosystems across Australia (Appendix E, Figure 22). It shows the ecosystems that use groundwater from beneath the water table or in the capillary zone. The dataset was created by analysing all vegetation polygons contained in existing maps, and the outcome of the analysis identified which of those polygons were potentially interacting with groundwater. The analysis initially identified vegetation polygons that were using another water source in addition to rainfall using remote sensing (MODIS and Landsat) data. These ecosystems are known as IDEs. The IDEs were then analysed further to determine whether the additional water source was likely to be groundwater, soil water or surface water. Where this additional information enabled a conclusion to be made on the potential of each vegetation IDE to be using groundwater, the ecosystem was included in the GDE layer ('Reliant on subsurface groundwater') and categorised as having either a high, moderate or low potential for groundwater interaction.

Other water dependent vegetation datasets

Department of Planning and Environment maintains the NSW BioNet, which is the repository for biodiversity data in NSW. It has 2 core applications – BioNet Atlas and BioNet Vegetation Classification. The BioNet Vegetation Classification includes spatial datasets on plant community types (PCTs), which is the master community-level typology used in NSW planning and assessment tools and vegetation mapping programs.

Two specific vegetation datasets were used in this study – the Sydney Urban Bushland Biodiversity (Pre-European) 1997 VIS_ID 4104 and the Southeast NSW Native Vegetation Classification and Mapping – SCIVI (VIS_ID 2230).

Species sightings – flora and fauna

The BioNet Atlas contains records of observations of plants, mammals, birds, reptiles, amphibians, and some fish, invertebrates and fungi (Appendix E, Figure 24). Each record contains various details, including geographic coordinates, information regarding the source and accuracy of the record and the time period within which a species was recorded at a particular location. Sightings of fauna and flora are constantly submitted for entry into the Atlas, and so the dataset will never be complete.

Atlas of Living Australia

A collaboration between CSIRO, Australia's museums and herbaria, universities, and the Australian Government established the Atlas of Living Australia (ALA); a national project focused on making biodiversity information accessible and usable. The ALA contains more than 85 million occurrence records, based on specimens from natural history collections, field observations and surveys (Appendix E, Figure 24).

Important bird areas

The Important Bird and Biodiversity Areas (IBA) program is an international non-governmental conservation scheme led by BirdLife International Partners such as BirdLife Australia. IBAs are sites of international importance for bird conservation. They are small enough to be practical targets for conservation management but large enough to meet the global IBA criteria. Three hundred and fourteen IBAs have been identified across Australia. A spatial data layer of IBAs was sourced from the Environment, Energy and Science group of Department of Planning and Environment (Appendix E, Figure 24).

Iconic species habitat mapping (part of community environmental values and uses)

Spatial datasets on the habitats of frogs, birds, bats and reptiles (Appendix E, Figure 25 to Figure 34) were derived from local species sightings acquired from the NSW BioNet and the ALA. The sightings were quality checked by subject matter experts at the former Office of Environment and Heritage and their associated networks, including those at the Australian Museum and universities. Sightings of species that were incorrectly identified were excluded (e.g. cane toad, *Rhinella marina*), as were sightings in locations that were unlikely habitats (e.g. along the roadside). The sightings for individual species were sorted into functional groups based on their habitat and water requirements. The requirements were then used to inform habitat cost–benefit models that predict the extent of suitable habitat for each functional group in the Wianamatta–South Creek catchment (Appendix B).

A.3 Datasets for Marxan

Hard urban surfaces

Recent urban developments in the Wianamatta–South Creek catchment have meant that some mapped habitats and species sightings no longer exist. To ensure our spatial datasets were current at the time of the study, we developed a spatial dataset of hard urban surfaces (Appendix E, Figure 35) and assumed that any mapped habitats and species sightings in these urban areas no longer existed. Any habitats and species sightings within the footprint of the new airport were also removed, based on advice from Infrastructure NSW.

The spatial dataset was developed by combining the following datasets and associated attributes:

- **NSW Landuse 2013**

All polygons classified as 'urban' under the major land-use category were selected and then filtered to exclude any urban areas with greenspace; that is, urban recreation, sewage ponds, golf courses, tourist development, universities and research facilities.

Building and other surfaced areas from agricultural areas were selected from the detailed land-use category. These included abattoirs, buildings associated with horticultural industry (winery, packing shed), farm infrastructure (house, machinery and storage sheds and garden areas), intensive animal production, intensive animal production – beef feedlot, intensive animal production – dairy shed, intensive animal production – piggery, intensive animal production – poultry, shade house or glass house (includes hydroponic use).

- **NSW Roads dataset, sourced from Department of Planning and Environment**

The NSW Roads dataset is made up of mapped lines categorised into specific road classes. The following classes were selected as they represent surfaced/paved roads: motor way, primary road, sub-arterial road, distributor road, and local road. The resulting lines were superimposed on the high-resolution imagery (see below) to assess road width, which was estimated to be 7 m. An additional buffer of 3.5 m was applied to generate polygons representing the surfaced roads.

- **High-resolution (10 cm) imagery provided by NSW Spatial Services, Department of Finance, Services and Innovation**

The most recent imagery available for the Wianamatta–South Creek catchment at the time of study was collected from 24/2/2016 to 03/05/2016.

- **Sentinel-2 multispectral image (January 2018) 10 m cloud free image collected on 30 January 2018, available from the Copernicus Open Access Hub**

A final step was to add in urban surfaces that had recently been developed, or otherwise not already captured in the NSW Landuse 2013 or NSW Roads datasets (e.g. university buildings surrounded by green space, within the 'universities and research' category). This was achieved by generating a vegetation index (NDVI, or Normalised Difference Vegetation Index) from the Sentinel imagery (NDVI = (NIR – R)/(NIR + R)). Areas with no vegetation cover were identified using the criteria NDVI = 0. These areas were reclassified from the NDVI raster and exported to an interim 'bare surfaces' polygon layer. The bare surfaces polygon layer was then superimposed on the high-resolution imagery (see above) and a true colour composite (RGB) from the Sentinel-2 (January 2018) 10 m imagery. Where polygons in the bare surfaces layer corresponded to urban surfaces in the high-resolution imagery or the Sentinel image, these were selected manually selected and included in the final hard urban surfaces dataset.

NSW National Parks and Wildlife Service estate

The NSW National Parks and Wildlife Service (NPWS) estate database provides information on areas reserved under the *National Park & Wildlife Act 1974* (Appendix E, Figure 36). Areas include national parks, nature reserves, regional parks, state conservation areas, Aboriginal areas, historic sites and karst conservation reserves.

Crown reserve estate

Crown reserves are land set aside on behalf of the community for a wide range of public purposes including environmental and heritage protection, recreation and sport, open space, community halls, special events and government services.

NSW more than 34,000 Crown reserves. The reserve management system enables the NSW Government, local councils and members of the community to work together to provide care, control and management over Crown reserves.

Ecological carrying capacity

This dataset accounts for the quality of terrestrial habitats supporting biodiversity and the connectivity of the habitats based on biological movement such as foraging, dispersal and migration (Appendix E, Figure 37). It is used in the NSW Government Biodiversity Indicator Program, as required under the BC Act. The dataset accounts for the carrying capacity of a landscape to support its original complement of biodiversity and ecosystems. It is part of a family of measures of the condition and connectivity of habitat, including its capacity to support the needs of native plants, animals and ecosystems in NSW, as a proportion relative to that in the pre-industrial era.

Appendix B – Developing spatial datasets

This appendix provides a summary of spatial datasets that were specifically developed in this study to fill the known gaps in mapping of high ecological value waterways and water dependent ecosystems in the Wianamatta–South Creek catchment.

Section B.1 of this appendix describes the development of the riparian and woody wetland vegetation datasets. Section B.2 describes the development of the non-woody wetlands dataset. Section B.3 describes the development of datasets on the habitats of iconic water dependent species. Section B.4 describes the spatial datasets for water quality and the Shannon–Wiener index, which were derived from the local field monitoring sites.

Maps of the final datasets used in the Marxan analysis are provided in Figure 3, Figure 4 and Appendix E, and tables of species lists, habitat requirements of iconic water dependent species, and datasets used to develop the maps are provided in Appendix F. Appendix G provides a list of the literature reviewed to develop the maps of habitats of iconic water dependent species.

B.1 Woodland riparian, woodland wetland and herbaceous wetlands

The woodland riparian, woodland wetland and herbaceous wetlands datasets include the vegetated areas of surface water dependent ecosystems (Figure 3 and Figure 4). This dataset was developed by combining 2 existing datasets available for Wianamatta–South Creek, according to the following decision rules:

1. Polygons mapped as native vegetation in the NSW State Vegetation Type Map were assigned a PCT from the revised Remnant Vegetation of the western Cumberland subregion, 2013 Update VIS 4207 (James 2018) dataset using a majority rule in which the PCT dataset occupying the majority of the polygon by area was assigned to the polygon.
2. Polygons mapped as ‘non-native’ in the NSW State Vegetation Type Map for vegetation community were retained as ‘non-native’.
3. If polygons were mapped as ‘Riparian woodland’ or ‘Non-woody wetland’ in the NSW State Vegetation Type Map but were to be assigned to a non-wetland or non-riparian vegetation PCT at decision rule 1, they were retained as ‘Riparian woodland’ or ‘Non-woody wetland’. This step was implemented to retain riparian and wetland polygons that were too small to be delineated in the coarser resolution dataset.
4. A reclassification was then applied to the output from decision rule 3 to categorise PCTs adopted from the dataset to riparian and wetland map units, according to the following:
    a. Coastal freshwater lagoons of the Sydney Basin Bioregion and South East Corner Bioregion to ‘non-woody wetlands’
    b. Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion to ‘riparian woodland’
    c. Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, Sydney Basin Bioregion to ‘woody wetland’
    d. all other PCTs to ‘other native vegetation’.

Decision rule 4 was guided by a review of the BioNet Vegetation Classification to identify vegetation communities with surface water dependencies. A PCT was identified to have surface water dependency if it was described as a ‘wetland’ or ‘riparian’ vegetation community in the BioNet Vegetation Classification database. A summary of map units, vegetation classes, endangered ecological communities and water dependencies is provided in Table 7 in Appendix F.

B.2 Open water wetlands

Areas of open water including natural and modified water storage areas, farm dams, and non-vegetated natural waterbodies (Figure 4) were not delineated in the NSW State Vegetation Type Map dataset or the revised Remnant Vegetation of the western Cumberland subregion, 2013 Update VIS 4207 (James 2018). To develop the mapping areas of open water, the output of decision rule 1 was superimposed on high-resolution aerial imagery collected in 2017–18 (see NSW_Imagery (MapServer)), and polygons corresponding to larger areas of open water but mapped as 'non-native' were identified and reclassified to the non-woody wetland dataset. Small farm dams were identified from the NSW Hydro Area Dataset and also added to the non-woody wetland dataset. A final set of farm dams that were not already identified were digitised from the high-resolution aerial imagery and added to the non-woody wetland dataset.

B.3 Habitats of iconic water dependent species

Maps of suitable habitats for iconic species of frogs, waterbirds and water dependent bats were developed using a cost–benefit mapping method, which combines measures of habitat suitability and connectivity to prioritise habitat (Drielsma et al. 2007). The method assumes a species will occupy and move across a landscape according to the shortest path or cost based on the species' requirements for foraging, breeding and shelter. An advantage of this method is that connectivity between waterways and other habitats (e.g. terrestrial vegetation) is included as a measure of habitat suitability. The method consists of a sequence of 4 steps, as outlined below. We applied the 4 steps of the method to produce maps of habitats for species within the same habitat groups (i.e. functional groups).

Limitations of the method are that it relies on scientific understanding and/or expert opinion of species habitat requirements. In many cases, species habitat requirements are not well documented, especially for the sites of interest in this study. Where species habitat requirements are known, the spatial datasets matching the requirement may be unavailable or limited in accuracy or currency. Many species are known to use fallen timber, for example, but mapping of fallen timber is not available for the Wianamatta–South Creek catchment. Similarly, many species require shallow water for foraging (waterbirds) or breeding (frogs), but datasets identifying water sources do not provide information on water depth. To help account for some of these limitations, we matched species habitat requirements to best available datasets, after consulting subject matter experts from the former Office of Environment and Heritage and their associated networks such as those at the Australian Museum and universities and an extensive review of the literature (Appendix G, Section G.2).

Step 1: Identify habitat requirements of iconic species through a review of the literature

Species lists for birds, frogs and water dependent bats were developed from sighting records held in the ALA, BioNet Atlas, local data collected by Blacktown City Council (bats) and schedules of threatened species under the BC Act and EPBC Act. These lists were checked and refined by subject experts to remove errors associated with misidentification of species and accuracy of the sightings data. The species were categorised into habitat groups according to their (similar) water and other habitat requirements.

A summary of the species identified (and sightings), their habitat requirements, and the assigned habitat use group is shown in Table 8 to Table 11 in Appendix F.

Step 2: Collate and prepare spatial datasets that characterise habitat requirements of iconic species

Several spatial datasets were collated to use as inputs for the 'water source' and 'landscape features' datasets (Appendix F, Table 12). The water source dataset brings together the sources of water in the landscape, and the landscape features dataset brings together more terrestrial features of the landscape that iconic species of frogs, birds and water dependent bats use for foraging, breeding and shelter. Note that the latter dataset is used to define the shortest path or cost of species moving and/or connecting with the water sources.

Step 3: Create integrated 'water source' and 'cost' datasets for each habitat group

Integrated 'water source' and cost datasets were generated for each habitat group (Appendix F, Table 13), using combinations of data selected from the spatial datasets listed in Table 12. The only exception was for the fishing bat, southern myotis, where sufficient information was available to create a dataset specifically for this species (as opposed to habitat groups). Table 13 provides a list of additional datasets that were available for generating habitat datasets for the bats.

All datasets identified in Table 12 in Appendix F were snapped to a 5 m Digital Elevation Model to provide a common grid for data preparation and spatial analysis. The datasets describing the landscape features were weighted with a cost to reflect the suitability of the landscape feature. Weightings (Appendix F, Table 13) were assigned heuristically using information from a review of the literature (Appendix G, Section G.2). Lower weightings (i.e. lower 'costs') are assigned to the landscape features that provide the most suitable habitat, and the highest weights assigned to unsuitable habitats.

Step 4: Develop habitat group maps for input to Marxan

Each habitat map was developed using a standard cost distance tool in ArcGIS 10.4. The cost distance tool calculates the least accumulative distance for each raster cell/grid of the cost dataset to the nearest water source. Figure 8 demonstrates how cost distance (c) is calculated from the water source dataset (a) and cost dataset (b) developed for the southern myotis. The cost distance dataset was further refined by selecting only those areas where the cost distance equalled 1 (d). This refined habitat suitability dataset was used as an input to Marxan.

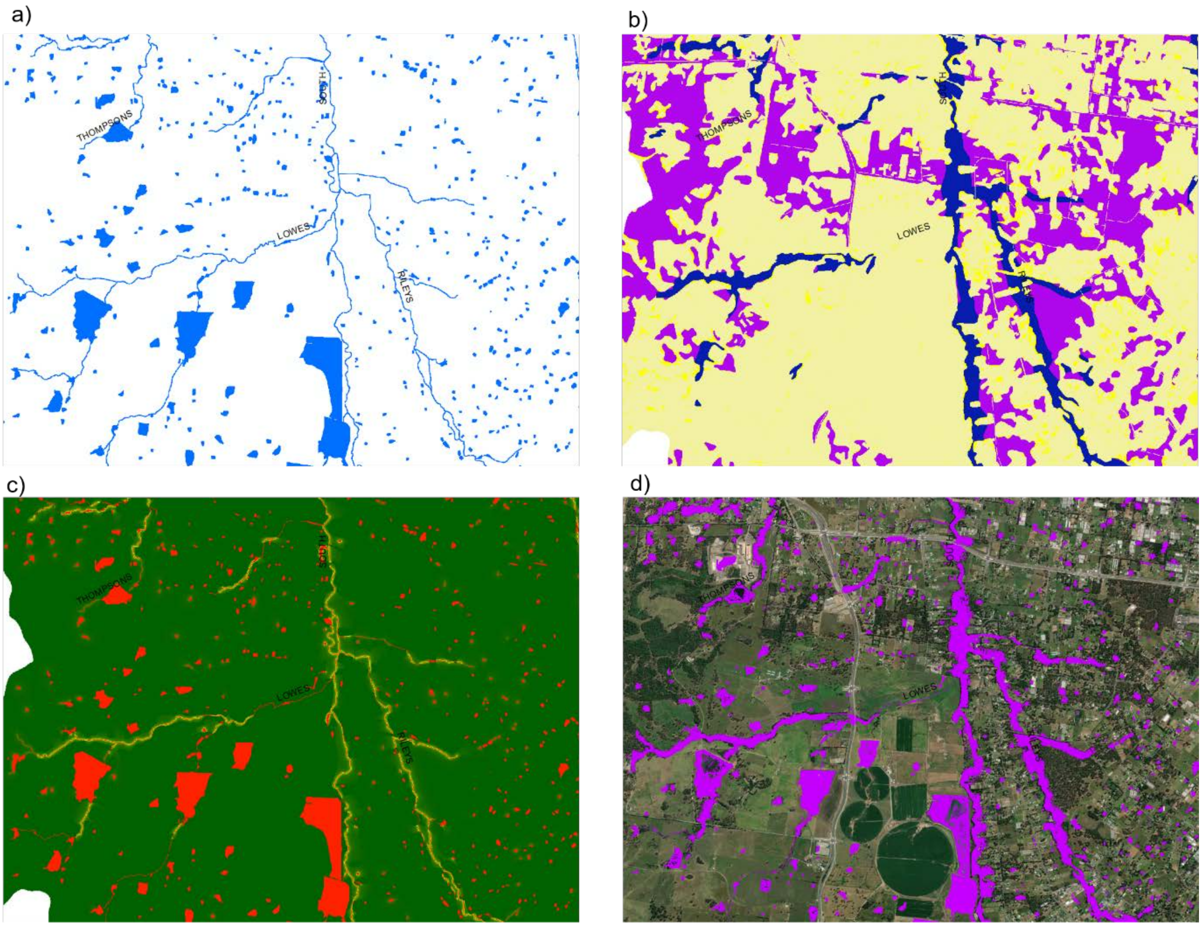

Figure 8 Integration of the water source (a) and cost (b) (blue least cost, yellow most cost) datasets to generate a range of suitable habitats (c) (red most suitable, green least) for Southern Myotis. Only the most suitable habitats (d) (purple) for Southern Myotis were used in the Marxan analysis

B.4 Water quality and Shannon–Wiener index

Local field measures of water quality and the derived Shannon–Wiener index (from the macroinvertebrates) were extrapolated to ≥3rd order streams in the Wianamatta–South Creek catchment using 2 spatial modelling tools developed by CSIRO and the National Oceanic and Atmospheric Administration for the United States Department of Agriculture. The 1st is a Spatial Tool for the Analysis of River Systems (STARS, version 2.0.4), which is needed to generate and format data to align with the stream network for the 2nd, Spatial Stream Network (SSN) tool. This 2nd tool specifically extrapolates the local field measures via a series of steps:

1. calculate pair-wise distances and spatial weights of the local field measures based on the stream network
2. check for autocorrelation that may be related to upstream and downstream influences
3. estimate (generalised linear) relationships between field measures and predictor variables to create the spatial datasets of water quality and Shannon–Wiener index.

Note, only the Shannon–Wiener index dataset (Appendix E, Figure 13) was used as an input to Marxan.

Data for STARS and SSN

Over 2,200 local field measurements were available for extrapolation. The field measurements were collected between 2005 to 2017, from 54 monitoring sites in the Wianamatta–South Creek catchment. The median, 20th and 80th percentiles of the field measurements were calculated and then used as inputs to STARS and the SSN tool. Table 4 provides a list of spatial datasets that were used as predictor variables in the SSN tool to extrapolate the field measurements to all 3rd order and greater streams in the Wianamatta–South Creek catchment. The list is aligned with the corresponding field measure that was extrapolated; for example, the land use, perennial nature of the streams and the condition of streams were predictor variables for the Shannon–Wiener index.

Extrapolations were successfully produced for the Shannon–Wiener index, chlorophyll *a*, dissolved oxygen, temperature, turbidity, ammonia, total nitrogen and total phosphorus. Extrapolations for field measures of pH and conductivity could not be produced due to the variability in the data. The predictor variables that were often strongly related to the water quality and Shannon–Wiener index were land use and the riparian vegetation condition.

Table 4 Datasets (and sources) used as predictor variables to extrapolate local field measurements to 3rd order streams in Wianamatta–South Creek

Field measure	Predictor variable	Data source
Shannon–Wiener index (macroinvertebrates)	Land use Perennial streams Stream reach condition	NSW Landuse 2013 Determining stream order fact sheet Ecological carrying capacity
Chlorophyll *a*	Land use Total nitrogen export to streams	NSW Landuse 2013 NSW estuary health risk dataset
Dissolved oxygen	Annual air temperature Water erosion hazard Perennial streams Stream reach condition	Bureau of Meteorology Land and Soil Capability Mapping for NSW Determining stream order fact sheet Ecological carrying capacity
Temperature	Land use Water erosion hazard Perennial streams Stream reach condition	NSW Landuse 2013 Land and Soil Capability Mapping for NSW Strahler stream order Ecological carrying capacity
Turbidity	Land use Water erosion hazard	NSW Landuse 2013 Land and Soil Capability Mapping for NSW
Ammonia	Land use Annual air temperature Water erosion hazard Perennial streams	NSW Landuse 2013 Bureau of Meteorology Land and Soil Capability Mapping for NSW Determining stream order fact sheet
Total Kjeldahl nitrogen	Land use Total nitrogen export to streams Total phosphorus export to streams Water erosion hazard	NSW Landuse 2013 NSW estuary health risk dataset Land and Soil Capability Mapping for NSW
Total nitrogen	Land use Water erosion hazard Stream reach condition	NSW Landuse 2013 Land and Soil Capability Mapping for NSW Ecological carrying capacity
Total phosphorus	Land use Water erosion hazard Stream reach condition	NSW Landuse 2013 Land and Soil Capability Mapping for NSW Ecological carrying capacity

Appendix C – Marxan

Marxan software is freely available to download. Version 2.43 was used for this study as it was the most recent at the time.

Marxan addresses the general problem of how to meet user-defined ‘management targets’ (Section 4.4, Table 2) for the minimum ‘cost’. Targets are the amount of each feature that the program is instructed to select (e.g. 30% of riparian vegetation). Costs are flexible, and can defined in terms of land value, resource harvest value, cultural value, spiritual value, cumulative impact and so on. High costs are applied to areas that should be avoided for protection. Other options that Marxan provides include the ability to determine the degree of compactness of selected areas (i.e. creating few large or many small areas for protection).

Marxan relies on a mathematical equation (not a model) to meet constraints with a number of good solutions. The algorithm answers the minimum set problem, which captures a minimum representation of features for the least cost. The objective is to minimise the total cost of the protect and improve areas and their total boundary, while meeting all management targets. The equation that Marxan uses is:

Score = Efficiency + BLM x Clumping + SPF x Target Shortfall

where:

Efficiency is the combined planning cost

BML is the Boundary Length Modifier

Clumping is the combined boundary length

SPF is the Specifies Penalty Factor

(Combined) target shortfall is a penalty for not achieving conservation targets

The solution with the lowest score is the one that Marxan selects as the ‘best’ solution – see Section C.2 below, which describes the Marxan results.

C.1 Setting up Marxan

To set up Marxan, the study area needs to be broken down into planning units, which are small geographic parcels of regular or irregular shapes such as hexagons, squares or hydrological drainage areas. In this study, we chose hexagons because they are more efficient than squares and hydrological drainage areas in producing compact/small protected areas. We also chose a hexagon size of 1 ha to correspond with the typical lot sizes of urban developments. Applying this configuration of planning units to the entire Wianamatta–South Creek catchment resulted in 63,710 planning units.

Each 1 ha hexagon was attributed area, length or occurrences of each of the blue elements listed in Table 1 (see Section 4.2) for defining high ecological value waterways and water dependent ecosystems. An example is shown in Figure 9 for the Lowes Creek tributary, where the planning units coloured in red are attributed with an area of 1 ha riparian vegetation because the spatial extent of the riparian vegetation covered (e.g. 9,261 m^2) almost the entire planning unit. By comparison, the planning units coloured in dark green have less area of riparian vegetation (e.g. 7 m^2).

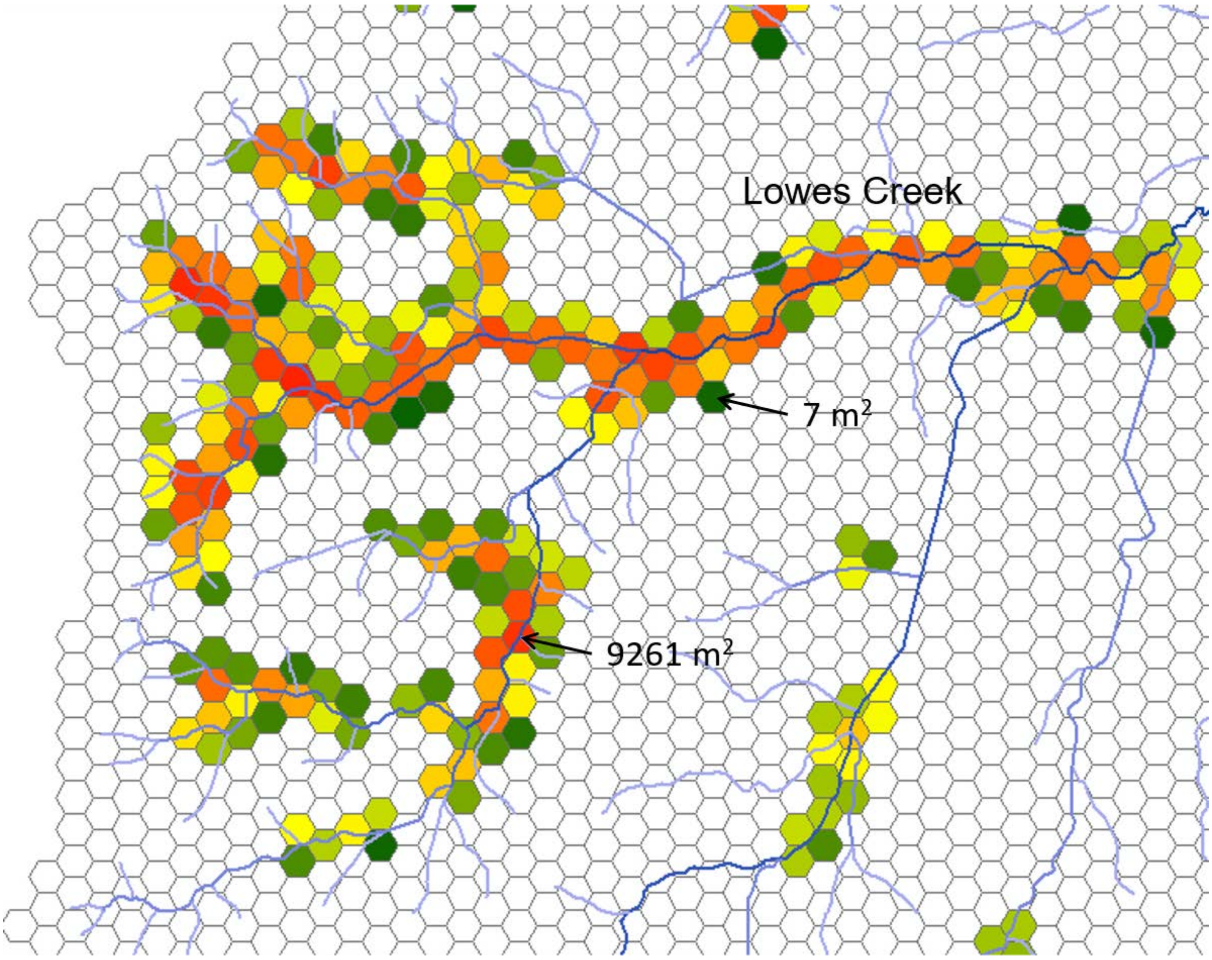

Figure 9 Lowes Creek tributary and surrounding catchment disaggregated into 1 ha hexagon planning units for use in Marxan

Datasets representing prioritisation criteria were also attributed to each 1 ha hexagon. These included the boundaries of the existing and acquired national parks estate in the Wianamatta–South Creek catchment, and the ecological carrying capacity of native vegetation (Appendix A, Section A.3). The national parks estate was used as a basis for determining complementarity, so that planning units selected outside of the existing protected areas complement those that are already protected. Planning units complement each other well if the species and habitats differ, so their selection provides a set of planning units, that when combined, achieve the goal of comprehensiveness in the most efficient manner.

The ecological carrying capacity of native vegetation was developed as an indicator of ecological integrity for the Biodiversity Indictor Program (OEH and CSIRO 2019), required under the BC Act. It was used in this study to ensure the principle of efficiency is met through relatively good condition and well-connected ecosystems. These 2 prioritisation criteria were particularly important given the general degraded state of the Wianamatta–South Creek catchment. Prioritising corridors that connect healthy ecosystems will assist populations to maintain genetic viability, provide access to larger habitats, which ensures a wider range of food sources and shelter, and provide an avenue for fauna to move or shelter in times of stress (e.g. resilience to climate change impacts). In this study, we used the ecological carrying capacity to quantify the ‘cost’ parameter in Marxan. This parameter literally defines the cost of including a planning unit in your final set of priority areas for protection. The lower the cost the more likely the planning unit will be included.

C.2 Explanation of Marxan outputs

Marxan produces 2 outputs – a best solution and a summed solution, which indicate how many and which specific planning units should be prioritised, respectively. The best solution can be interpreted as the 'best' solution for priority areas for protection when comparing all solutions determined from a specified number of times Marxan is run. In this study we ran Marxan 100 times, meaning that our best solution was determined from 100 possible solutions. We chose 100 because this number of runs provides adequate repetition while minimising the overall run time when using large and complex datasets. In Marxan, the best solution is determined by a score that is calculated for each planning unit. The score is indicative of the extent to which the management target for each indicator and other conservation principles (e.g. complementarity) is met while minimising costs (i.e. ecological carrying capacity). The lower the score for each planning unit, the better. The algorithms in Marxan will compare the 100 combinations of planning units arising from the 100 runs and determine the best solution from the combination resulting in the overall lowest score.

The summed solution shows how often each planning unit is selected for inclusion in protected areas. The outputs are percentages based on selection frequency; for example, if a planning unit was selected 50 times out of the 100 runs, the frequency of selection is 50%. Planning units that are rarely selected can be ignored because they do not meet all the management targets and other conservation principles. The selection frequency cut-off is usually 50% (see below).

C.3 Priority areas for protection and priority areas for improvement

In this study we used the selection frequency to define our cut-offs for priority areas for protection and priority areas for improvements. The plots provided in Figure 10 compare the selection frequency and the proportional extent (area or length) of each indicator for waterways and water dependent ecosystems. The proportional extent of each indictor markedly decreases at a selection frequency cut-off of around 80%. The next marked decrease occurs at a selection frequency cut-off of 50%. Intuitively, we identified priority areas for protection based on the 80% cut-off, and priority areas for improvement based on the 50% cut-off.

Figure 11 provides a close-up of our priority areas for protection or improvement around the Badgerys Creek and Thompsons and Lowes Creek tributaries and their connection to Wianamatta–South Creek itself. All of Badgerys Creek has been prioritised for protection, as have the upper reaches of Thompsons Creek. Smaller tributaries and stands of groundwater dependent ecosystems (vegetation) lie between the 2 creeks and these have been prioritised for improvement. Much of the lower parts of Thompsons Creek itself have been prioritised for improvement and will provide the important connection to Wianamatta–South Creek. Within the areas for improvement are potential habitats for waterbirds, frogs and water dependent bats.

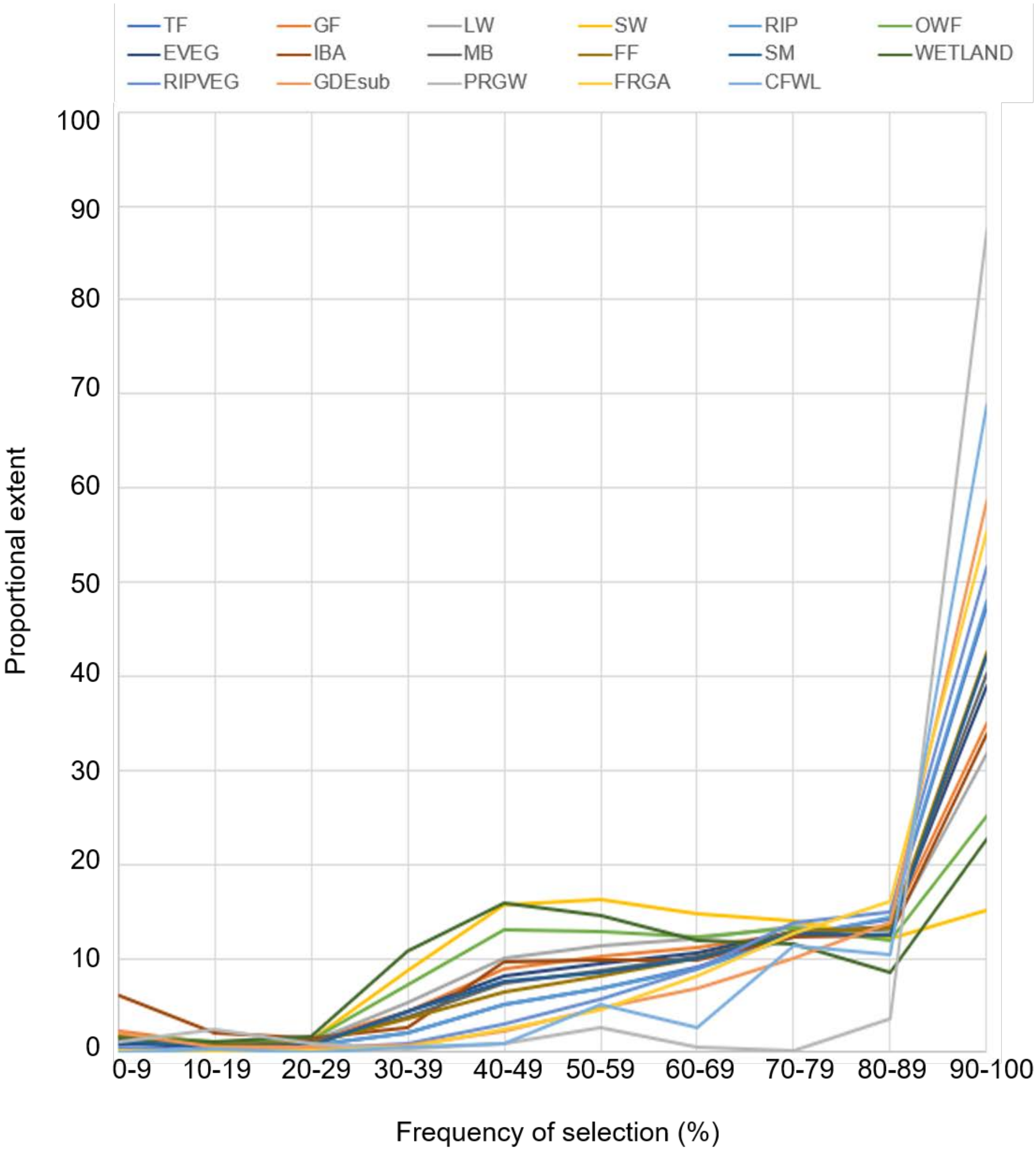

Figure 10 Thresholds used to define protect and improve areas in the map, based on the proportional extent of each blue element in a planning unit and the frequency of selection of the planning unit

TF = tree frogs, GF = ground dwelling frogs, LW = large wader birds, SW = small wader birds, RIP = waterbirds dependent on riparian vegetation, OWF = open water bird foragers, EVEG = emergent vegetation bird forages, IBA = important bird habitat, MB = microbats, FF = flying-fox, SM = Southern Myotis, WETLAND = woody and non-woody wetlands, RIPVEG = riparian vegetation, GDEsub = groundwater dependent ecosystems (accessing aquifers), PRGW = Parramatta River red gum, FRGA = forest red gum, CFWL = coastal freshwater lagoons.

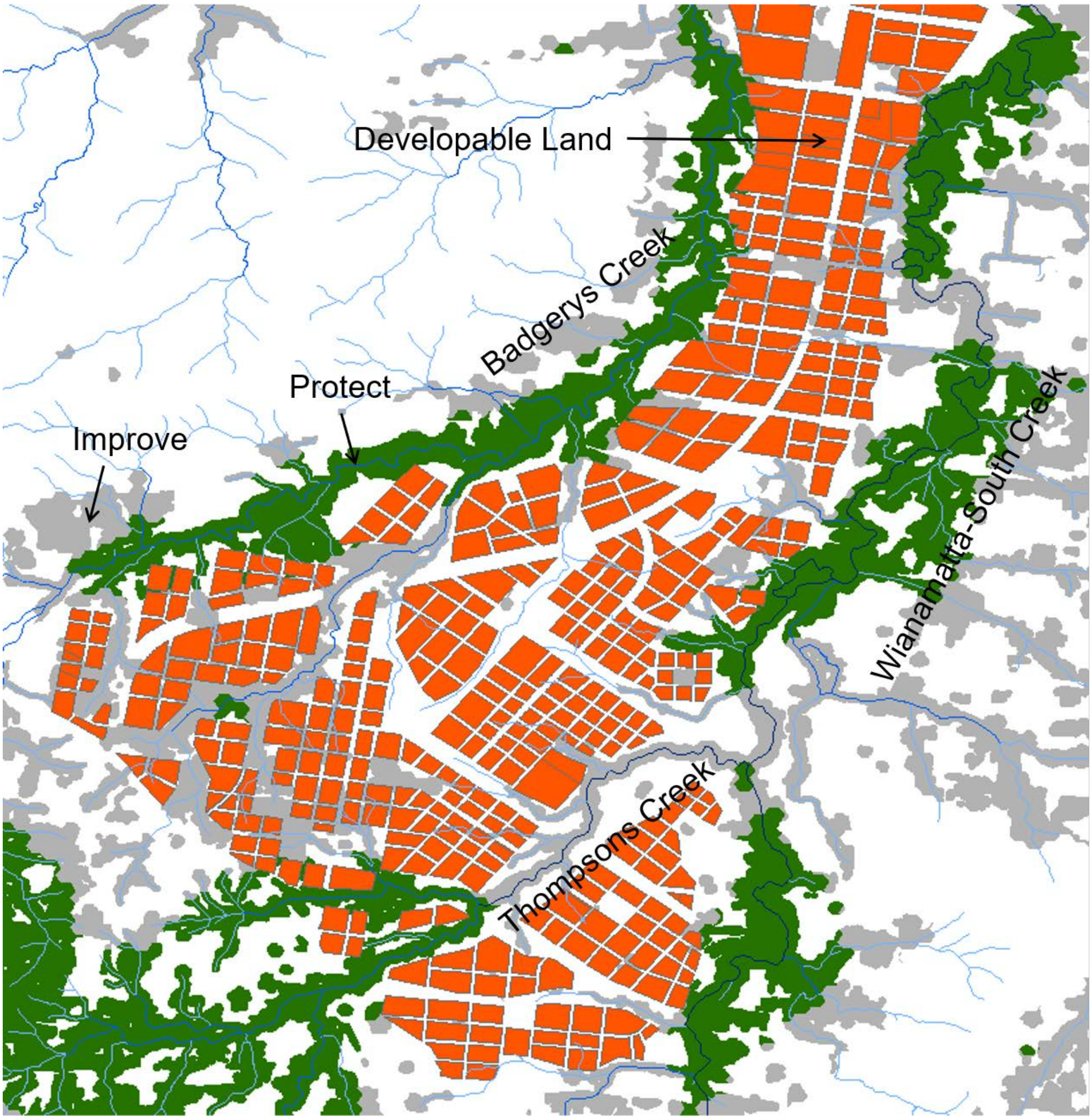

Figure 11 **Map of the Aerotropolis Core Precinct showing the connection between the protect and improve areas of high ecological value waterways and water dependent ecosystems**

Appendix D – Ground truthing

The map of high ecological value waterways and water dependent ecosystems was ground truthed (otherwise known as map accuracy assessment) by comparing independent field measurements with the map attributes at the same locations. The amount of agreement between the attributes and field measurements was evaluated using confusion matrices and the kappa statistic. This accuracy assessment is a standard method, and follows the methods outlined by Stehman and Czaplewski (1998). The following sections describe the selection of field measurement locations, and detailed descriptions of the accuracy of the overall map and individual datasets making up the map.

D.1 Locations for ground truthing

The locations of field measurements were determined initially through desktop assessment, which involved selecting a subset of the 1 ha hexagons (planning units) that make up the planning grid structure of the map (Appendix C, Figure 9). The selection was via a stratified random sampling approach to ensure field measurements are obtained from areas mapped as high ecological value and those that fall outside of the map because they have no or relatively little ecological value. An initial screening of the 1 ha hexagons was undertaken to rapidly assess whether the map accurately captured areas of no or low ecological value. The screening was done through air photo interpretation, in which the selected 1 ha hexagon was superimposed on very high-resolution aerial imagery collected in 2017–18 by NSW Spatial Services at the Department of Finance Services and Innovation. The 1 ha hexagon was classed as no or low ecological value if the area contained sporting fields, buildings, car parks and/or streets. If the 1 ha hexagon could not be classified, it was selected as part of the subset of 1 ha hexagons requiring a field/on-ground measurement. The final subset of 1 ha hexagons was then constrained by (safe) accessibility to the locations on ground and permissions by landholders to access their properties.

The locations of the final subset of 1 ha hexagons were provided to field staff to assess the presence or absence of the individual map attributes (see Section D.2). The field staff were not informed of whether the location fell within an area attributed as high ecological value or not on the map, to ensure the field measurements were as independent as possible.

D.2 Field measurements

The field measurements were completed by subject matter experts and field practitioners:

- Presence or absence of key fish habitat was determined by Fisheries Officers at the Department of Planning and Industry – Fisheries and specialist aquatic ecologists at the Environment, Energy and Science Group of Department of Planning and Environment.
- Assessments of the River Styles Recovery Potential, Geomorphic Condition, and River Style Type were undertaken by geomorphologists, who conducted preliminary surveys to familiarise themselves with the catchment and then used desktop assessments including air photo interpretation, terrain modelling and stream sinuosity measures to complete the analyses.
- Vegetation assessments were undertaken by accredited vegetation ecologists. Rapid vegetation surveys were used to determine the presence or absence of native vegetation. If one or more native vegetation communities were present, a 20 x 20 m vegetation survey plot was placed within the 1 ha hexagon to determine PCTs according to the NSW BioNet Vegetation Classification database.

Additional vegetation datasets were sourced and adopted into the accuracy assessment, in cases where the data was found to be independently collected (i.e. unrelated to the vegetation mapping projects) and consistent with the accredited survey plot sampling method. These additional vegetation datasets included:

- vegetation survey plots from the NSW BioNet Systematic Flora Survey database
- recently collected vegetation survey data provided by the Conservation and Sustainability Branch of Department of Planning and Environment.

In cases where the vegetation plot data provided complete coverage of the 1 ha hexagon, the data were included into the overall map accuracy assessment (see Section D.3). All vegetation survey plot data were included to assess the accuracy of the relevant individual spatial datasets making up the map, such as the riparian vegetation and woody wetland datasets (Section D.4).

A total of 396 field and desktop measures were used for the accuracy assessment (Table 5). These fell within a total of 161 1 ha hexagons.

Table 5 Number of field measures (sampling sites) used for assessing the accuracy of datasets underpinning the map of high ecological value waterways and water dependent ecosystems

Attribute	Method	New field measures	Existing field measures	Total number of field measures
Key fish habitat	Field	60	0	60
River Styles	Field and desktop	68	0	68
Vegetation plots	Field	136	66	202
Attribution of 1 ha hexagons as having high ecological value or not	Desktop	66	0	66
Total number of field measures used in accuracy assessment		330	66	396
Total number of 1 ha hexagons used in accuracy assessment				*161

* Multiple vegetation plots were used to assess the accuracy of a single 1 ha hexagon, and therefore total assessments of hexagons versus field measures is different.

D.3 Overall accuracy of the map

The overall accuracy of the map was high according to the percentage of agreement between the field measurements and mapped attributes (93.2%), and the kappa statistic (0.86 ± 0.04). Only a small number of 1 ha hexagons were incorrectly attributed as having no or little ecological value, indicating a very low omission error (Table 6). Commission error was even lower, with only two 1 ha hexagons incorrectly attributed as having high ecological value. Most of the 1 ha hexagons attributed as having ecological value were correctly classified into the protect areas of the map. Field measurements also confirmed that the 1 ha hexagons classified as improve areas in the map still contained ecological value but to a lesser degree.

Table 6 Overall accuracy of the map of high ecological value waterways and water dependent ecosystems and attributes

Map and attributes	Overall accuracy (%)	Kappa statistic ± standard error
High ecological value waterways and water dependent ecosystems – overall	93.2	0.86 ± 0.04
Key fish habitat	84.9	0.06 ± 0.06
River Styles – geomorphic condition	55.6	0.04 ± 0.09
River Styles – recovery potential	38.3	0.11 ± 0.07
River Styles – type	51.1	0.08 ± 0.07
Endangered ecological communities (PCTs)	67.5	0.54 ± 0.04
Riparian vegetation and wetlands	84.3	0.63 ± 0.05

D.4 Accuracy of the individual map attributes

The accuracy of the individual datasets that make up the map were also assessed, as they provide an indication of the sources of error. It is important note, however, that many of the individual datasets have been produced by other agencies for specific purposes. This means the accuracies presented below are relevant only to the interpretation of the map of high ecological value waterways and water dependent ecosystems.

Key fish habitat

A total of 126 1 ha hexagons were independently assessed for the presence or absence of key fish habitat. There was good agreement between the field measurements and the mapped key fish habitat, with an accuracy of 84.9% (kappa statistic = 0.69 ± 0.06).

River Styles

Many streams in the Wianamatta–South Creek Catchment were not mapped in the River Styles dataset. While assessment was therefore limited to mapped streams, it still showed low agreement between the field measurements, and the River Styles areas were found to have low agreement with the mapped River Styles type (51%, kappa statistic = 0.08 ± 0.07), geomorphic condition (38%, kappa statistic = 0.11 ± 0.07) and recovery potential (38%, kappa statistic = 0.11 ± 0.07). This is primarily due to incorrect ‘absences’ of the River Style attribute; for example, the most important River Styles type in the Wianamatta–South Creek catchment requiring protection is the ‘chain of ponds’. Very few chains of ponds are identified in the River Styles map compared to the number observed in the field. It is worth noting however that the location of the mapped chains of ponds were accurately confirmed and that other attributes in our map of high ecological value waterways and water dependent ecosystems ensured the locations of the unmapped chains of ponds were included in the protect areas anyway.

Endangered ecological communities (water dependent vegetation)

The accuracy of the individual PCTs in the vegetation dataset (see Appendix A) was assessed as these correspond to the endangered ecological communities, which were included in the map of high ecological value waterways and water dependent ecosystems. A full list of the PCTs and their name codes, corresponding map unit, and dependencies on water is shown in Table 15 of Appendix F.

A comparison between the field measurements and mapped PCTs indicates a moderate accuracy of 67.5% (kappa statistic = 0.54 ± 0.04). The largest source of error occurred in areas that were mapped as non-native but were assessed as native in the field. Some of this omission error is likely to be a result of small patches of native vegetation not being large enough to be identified for inclusion in the vegetation dataset.

Riparian vegetation and wetlands

Field measurements from the vegetation plots within the 1 ha hexagons were grouped into either water dependent (riparian and wetland) or not water dependent and compared to the mapped riparian vegetation and wetland datasets developed for this study. The results suggest good agreement, with an accuracy of 84.3% (kappa statistic = 0.63 ± 0.05).

Appendix E – Maps of datasets

This appendix provides maps of the final datasets that were used in Marxan. Descriptions of the datasets and their sources are provided in Appendix A. The datasets are presented in the same order as they are described in Appendix A.

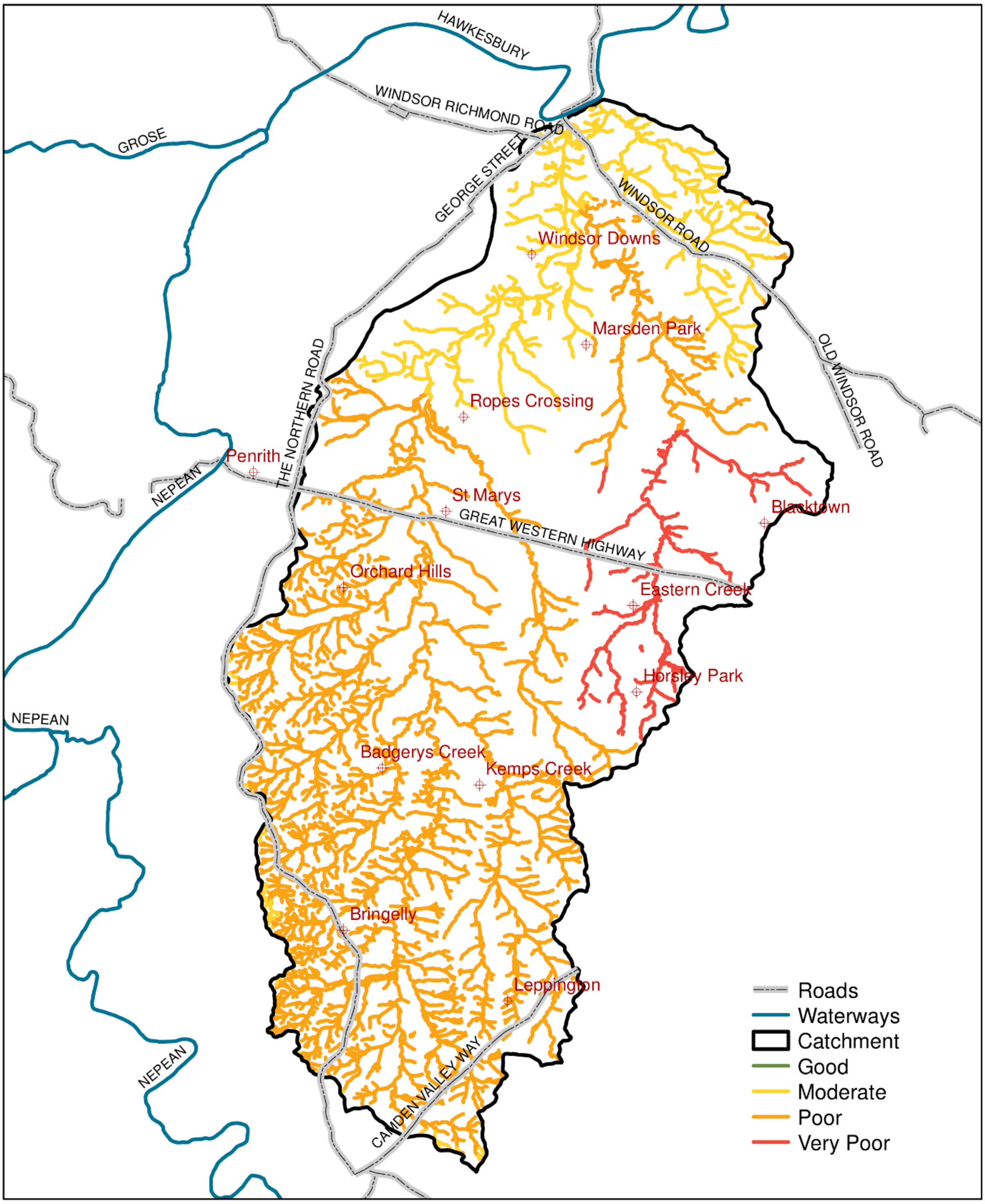

Figure 12 River condition index

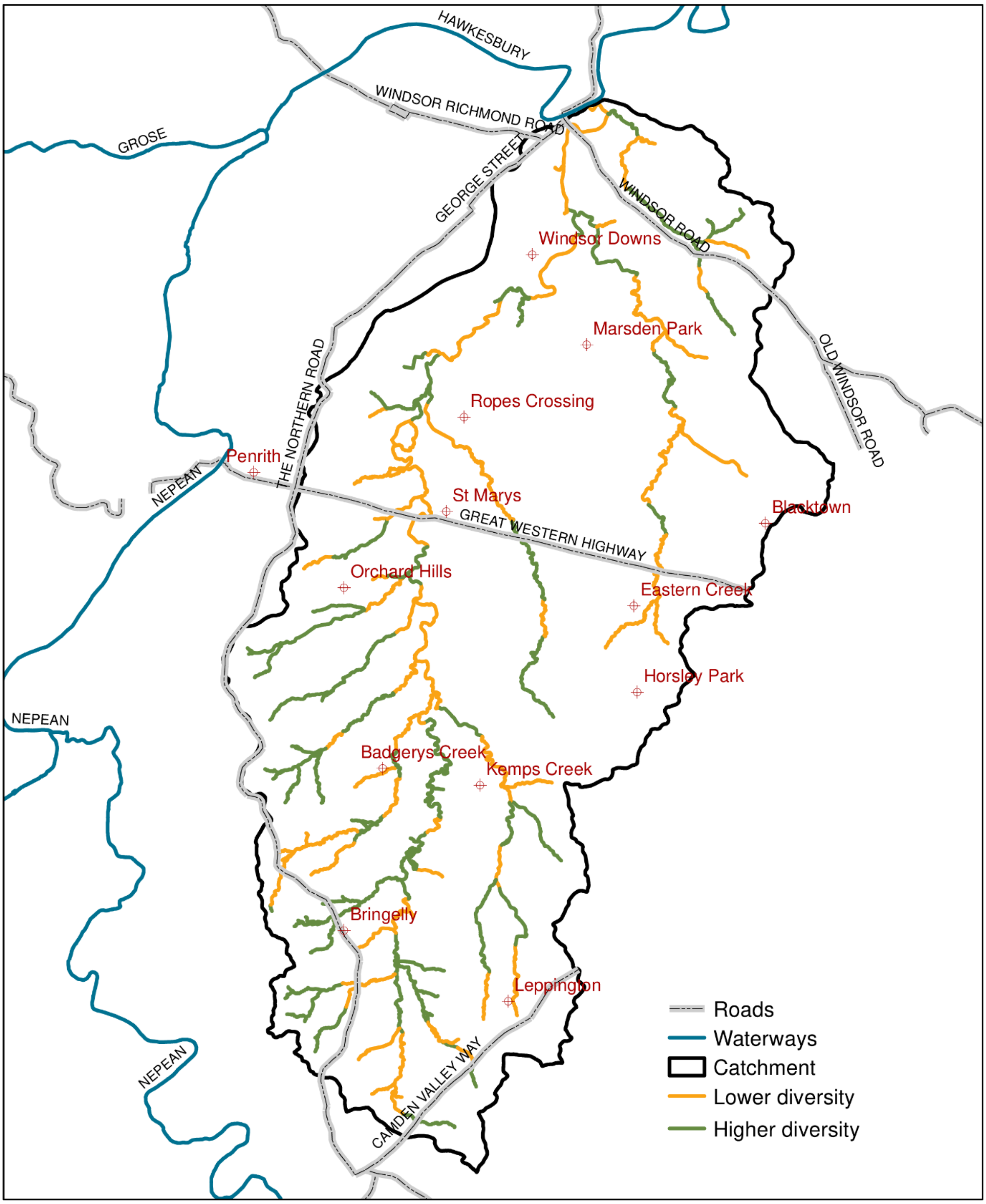

Figure 13 Shannon–Wiener index

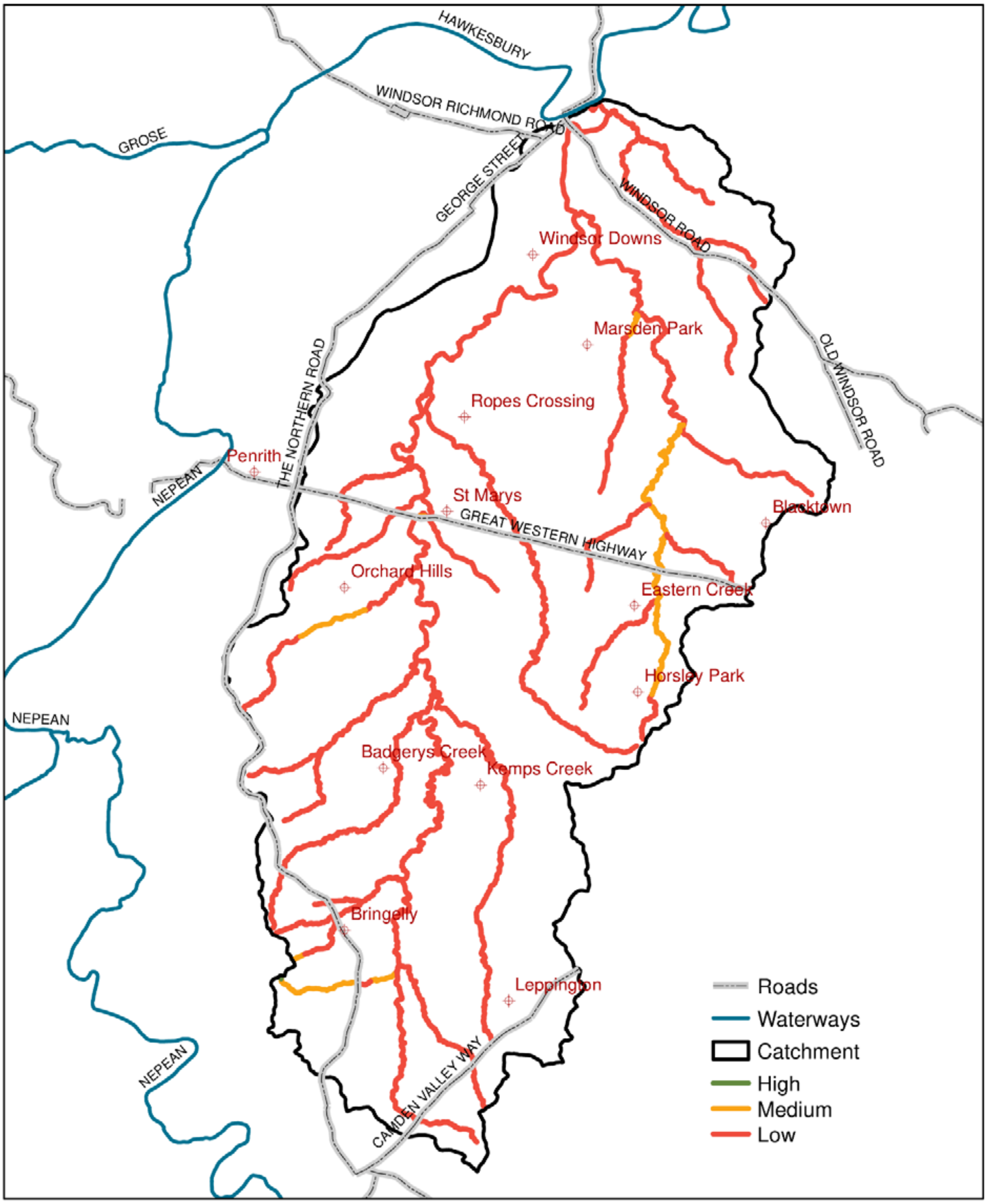

Figure 14 High ecological value aquatic ecosystems

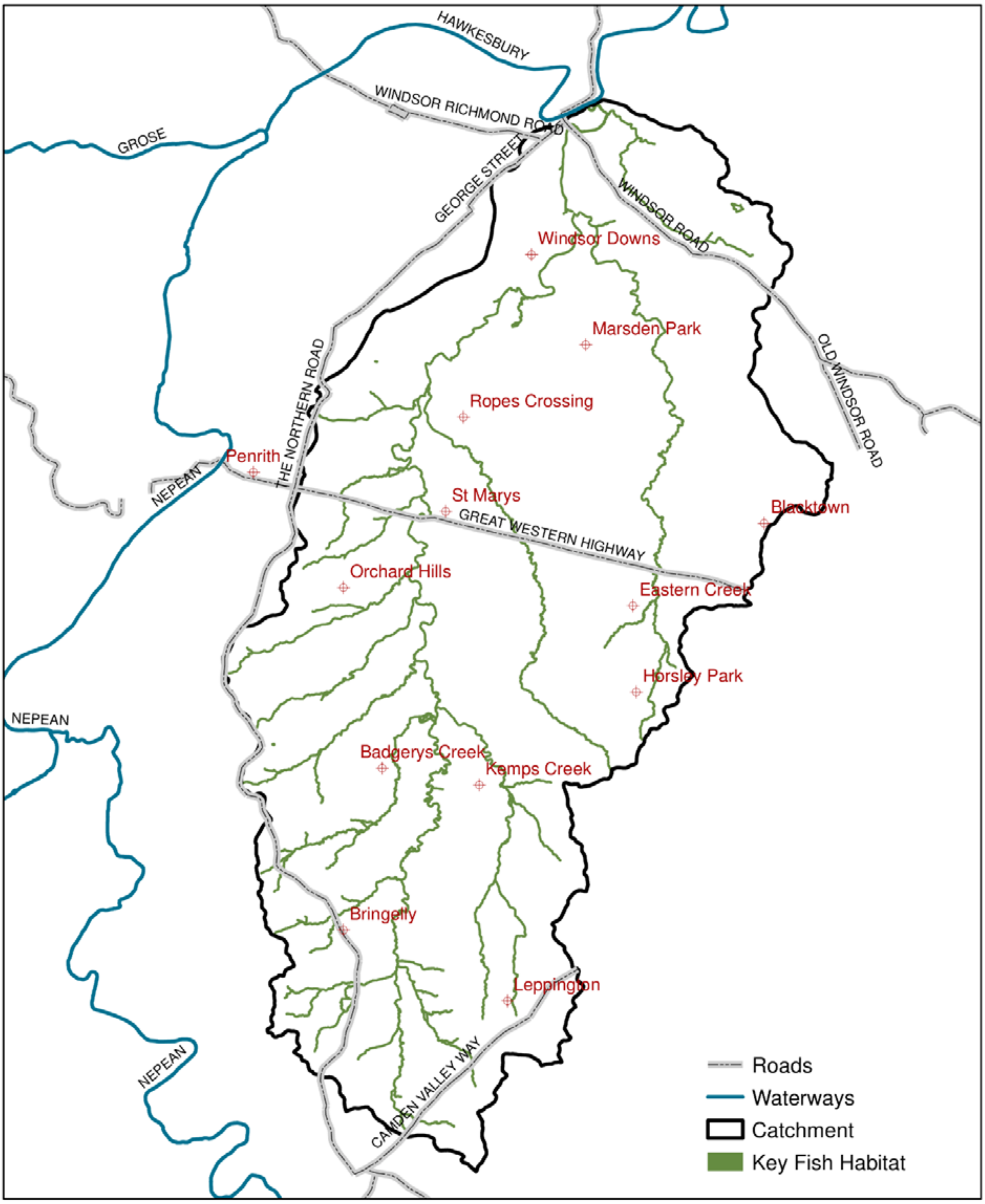

Figure 15 Key fish habitat

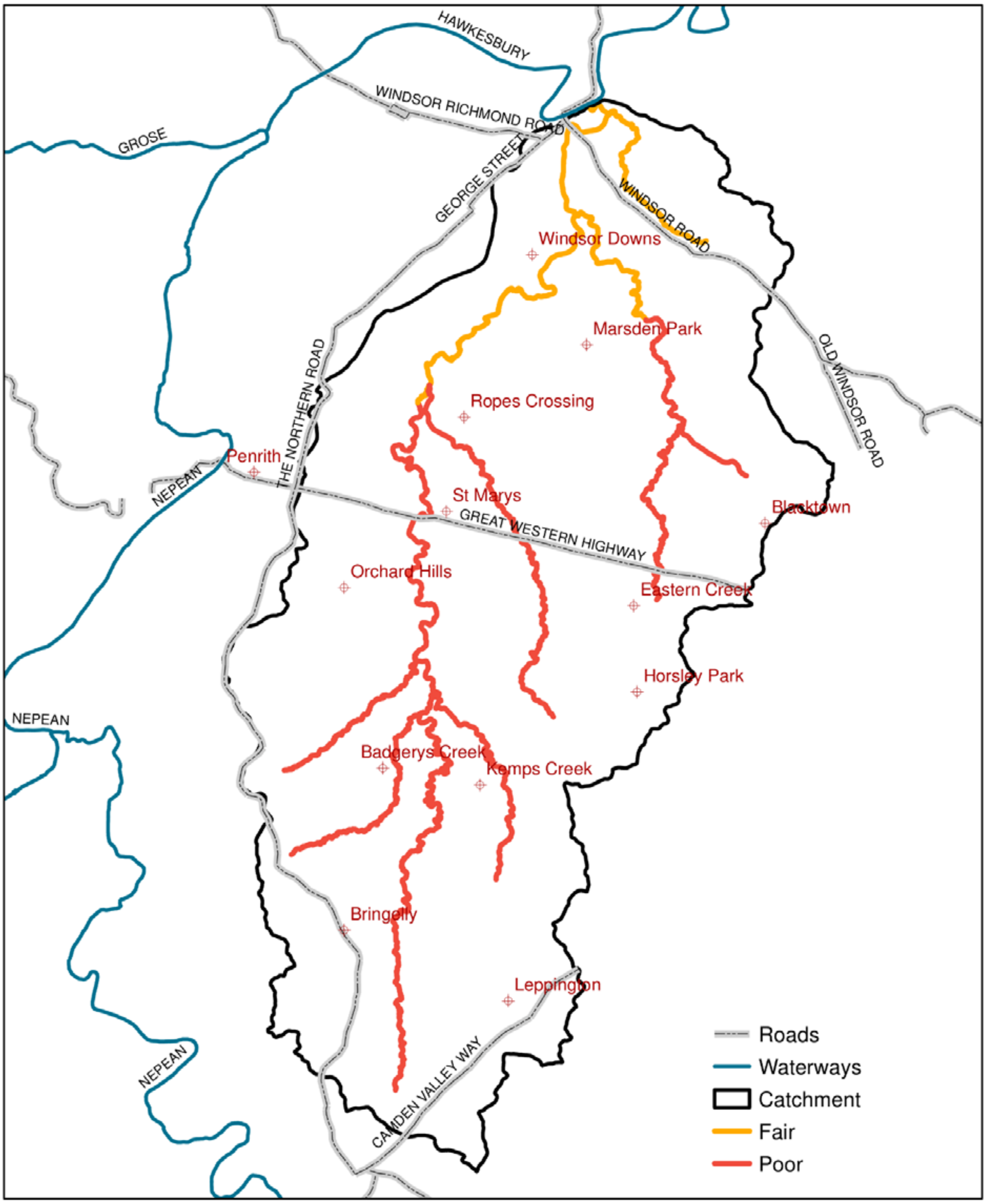

Figure 16 Fish condition

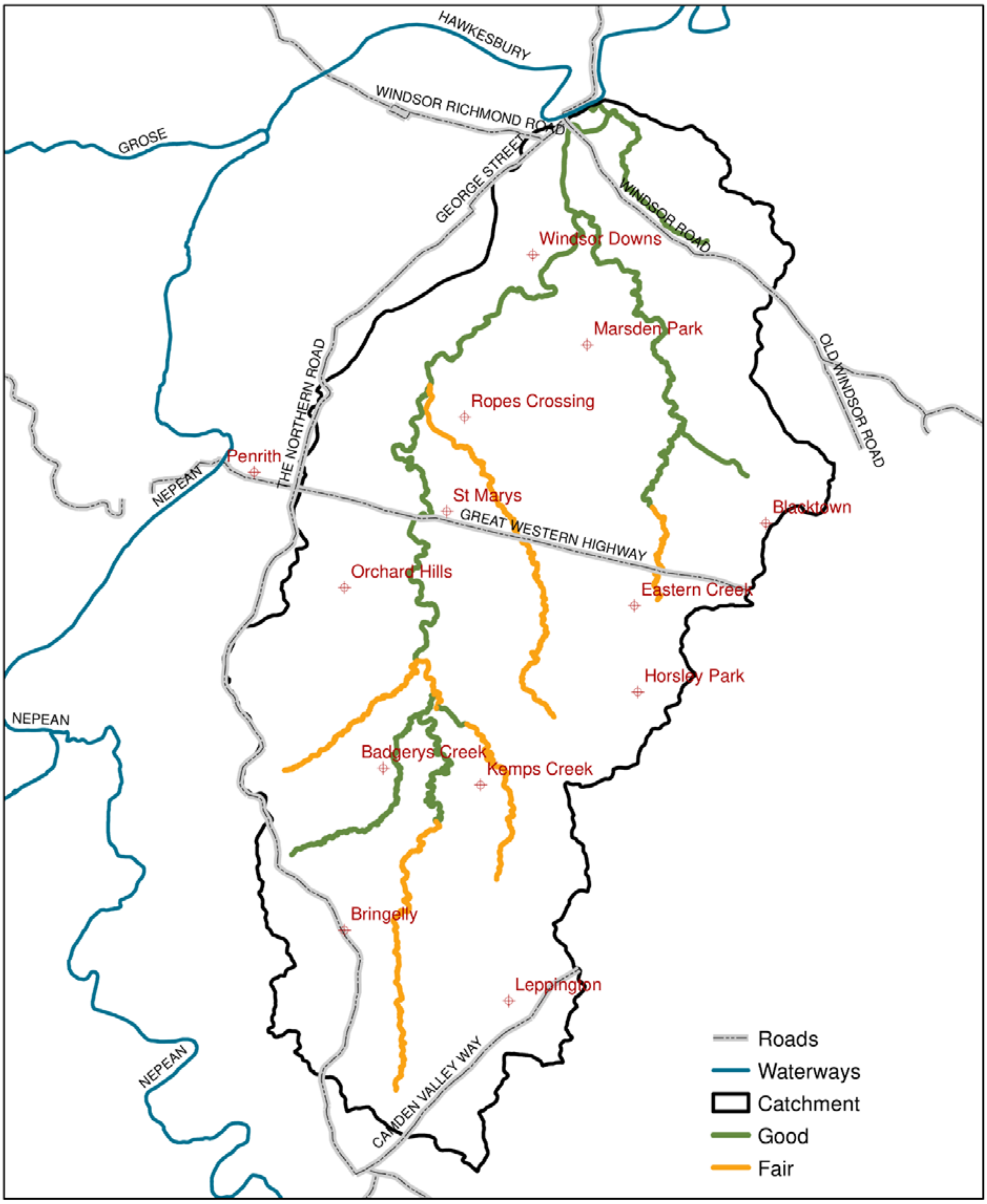

Figure 17 Fish nativeness

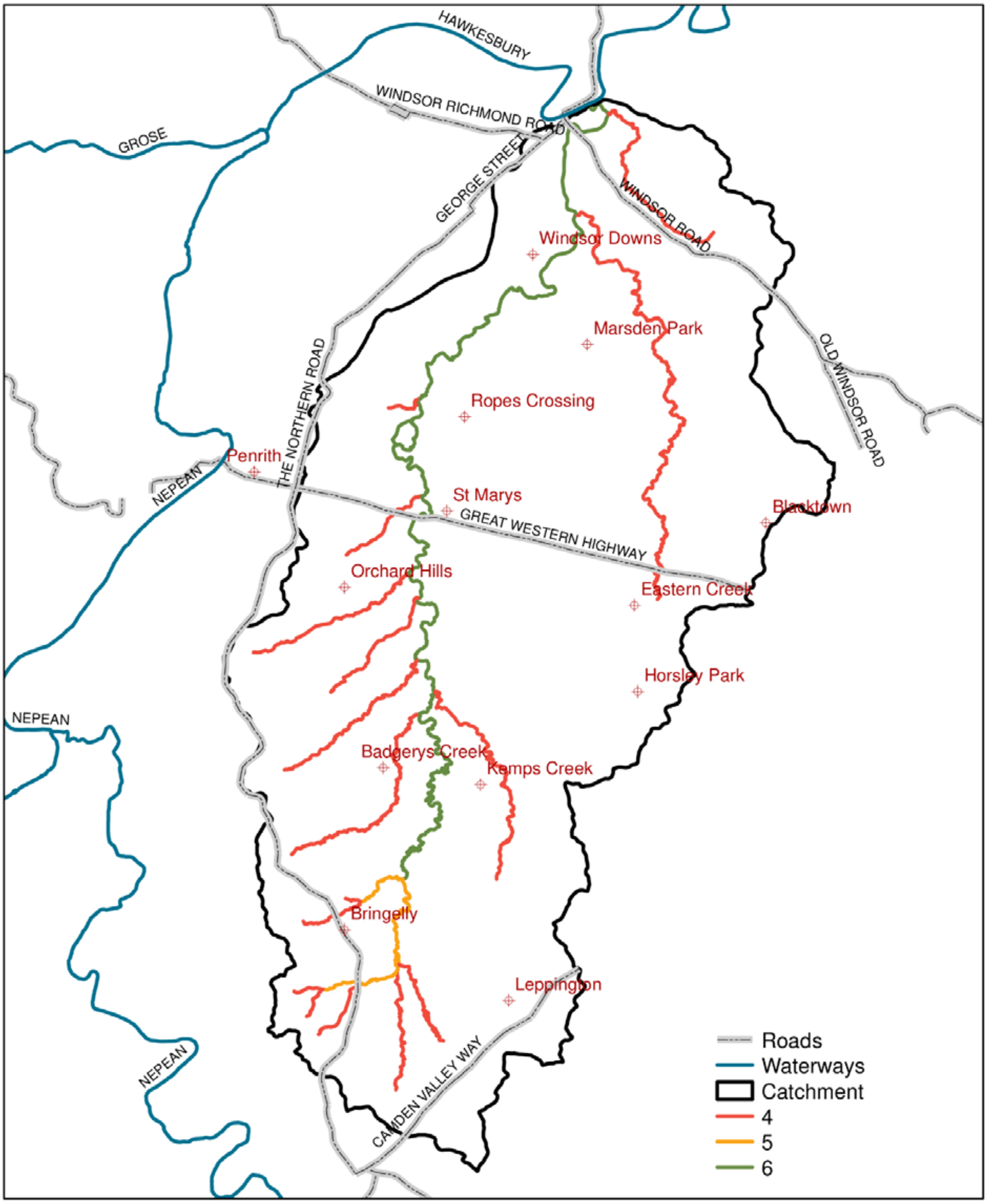

Figure 18 Strahler stream order, greater than or equal to 4th order streams

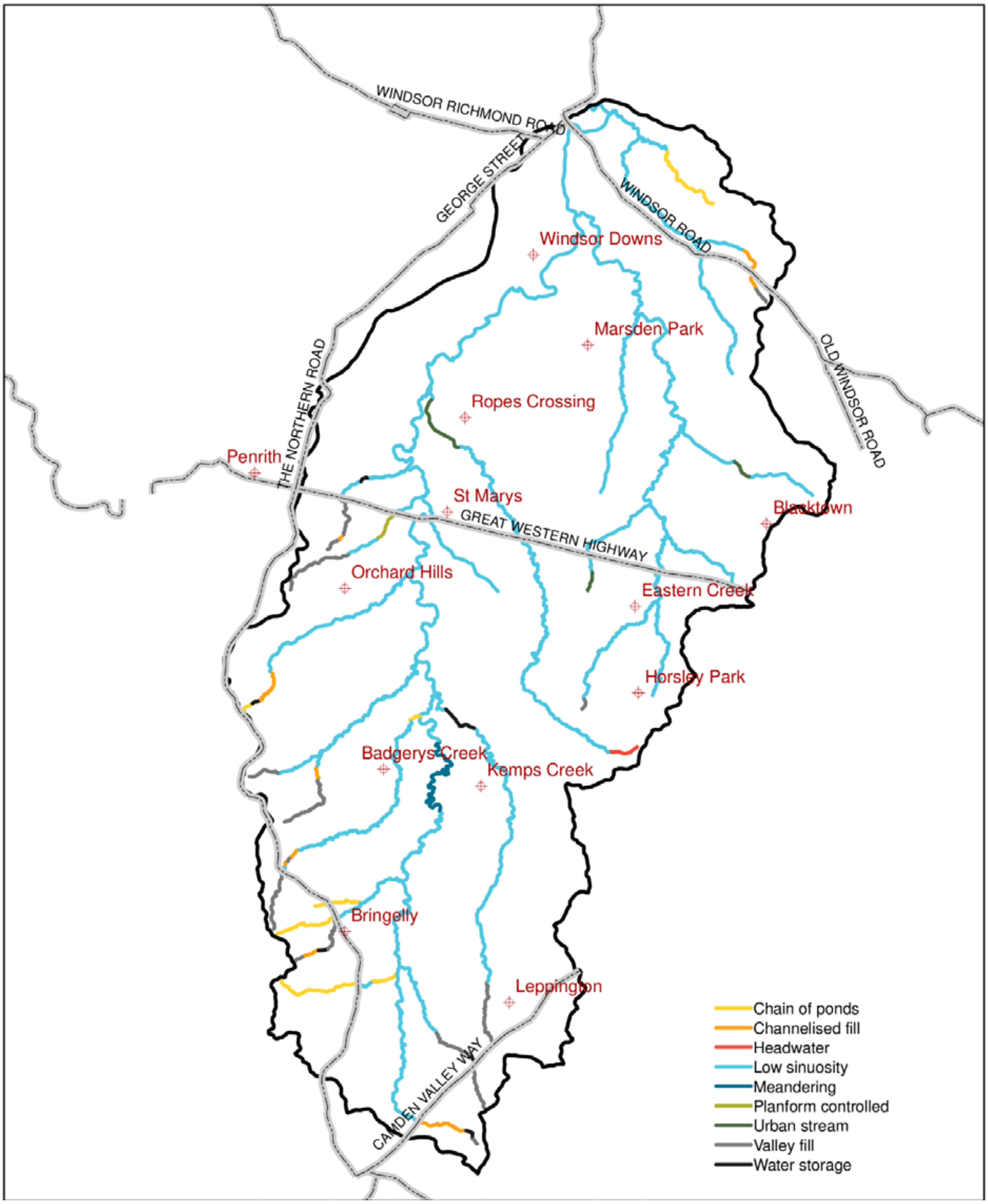

Figure 19 River Styles type

Only chain of ponds was included in Marxan.

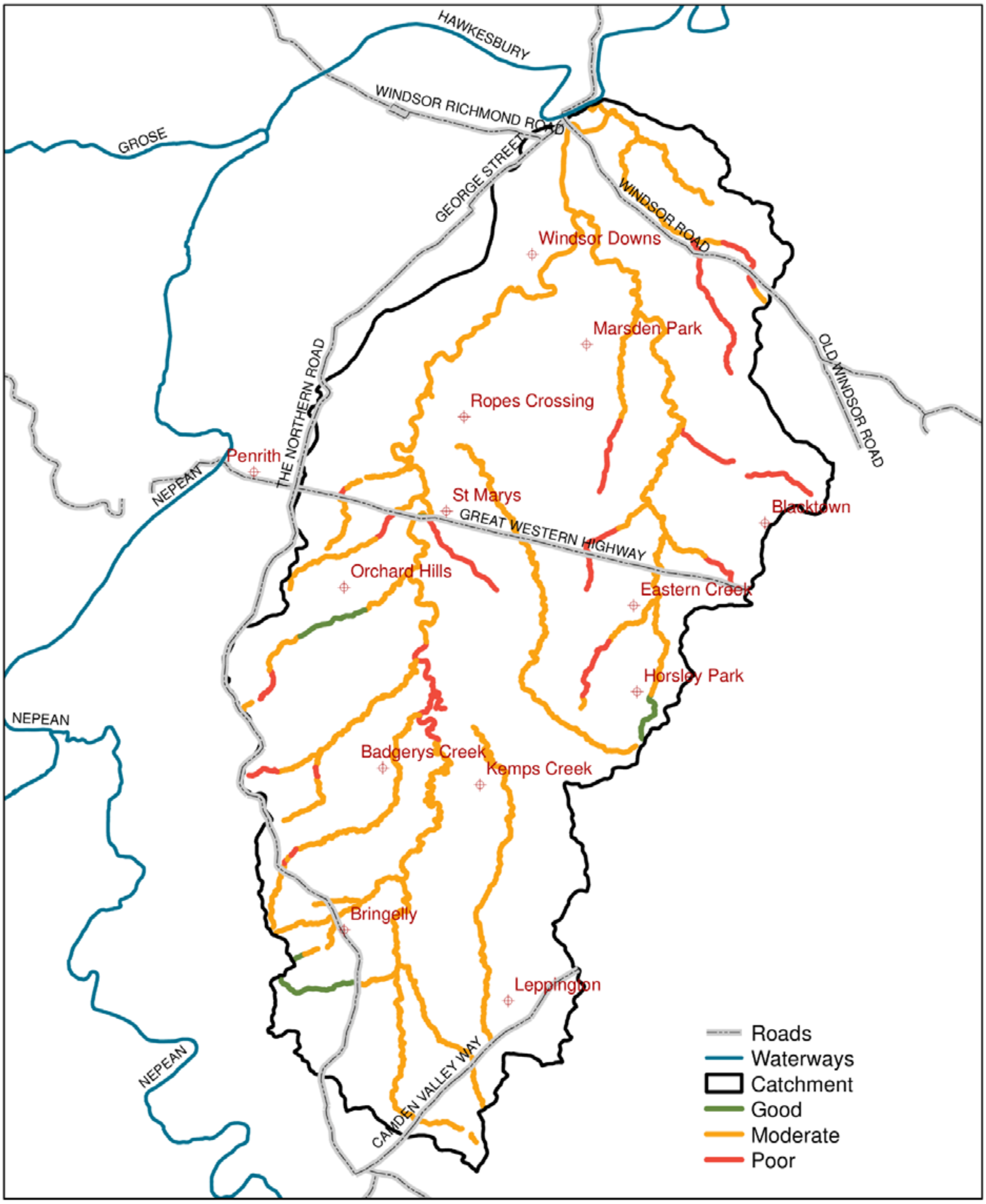

Figure 20 River Styles geomorphic condition
Only good and moderate condition were included in Marxan.

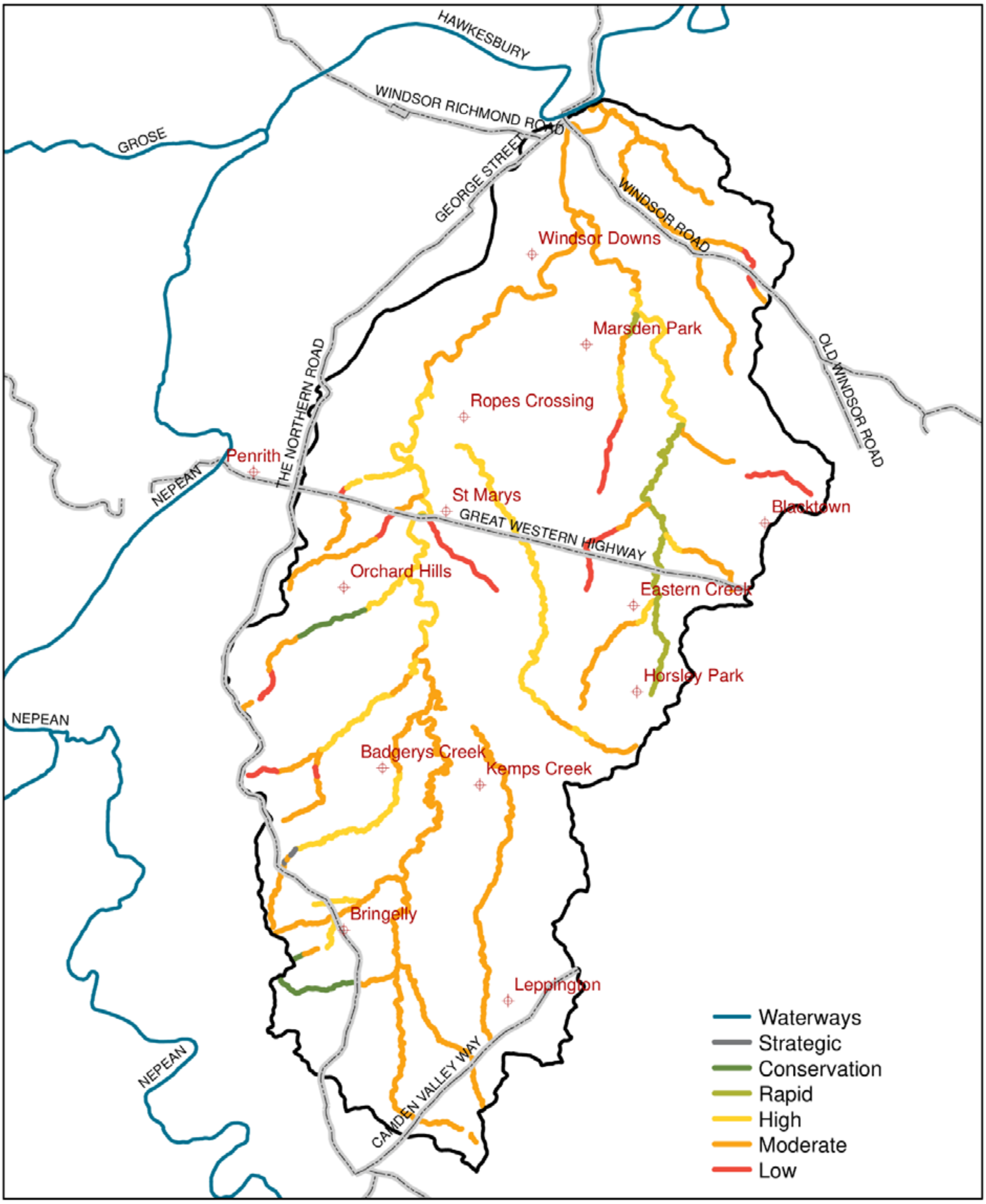

Figure 21 River Styles recovery potential

Only conservation, rapid, high and moderate were included in Marxan.

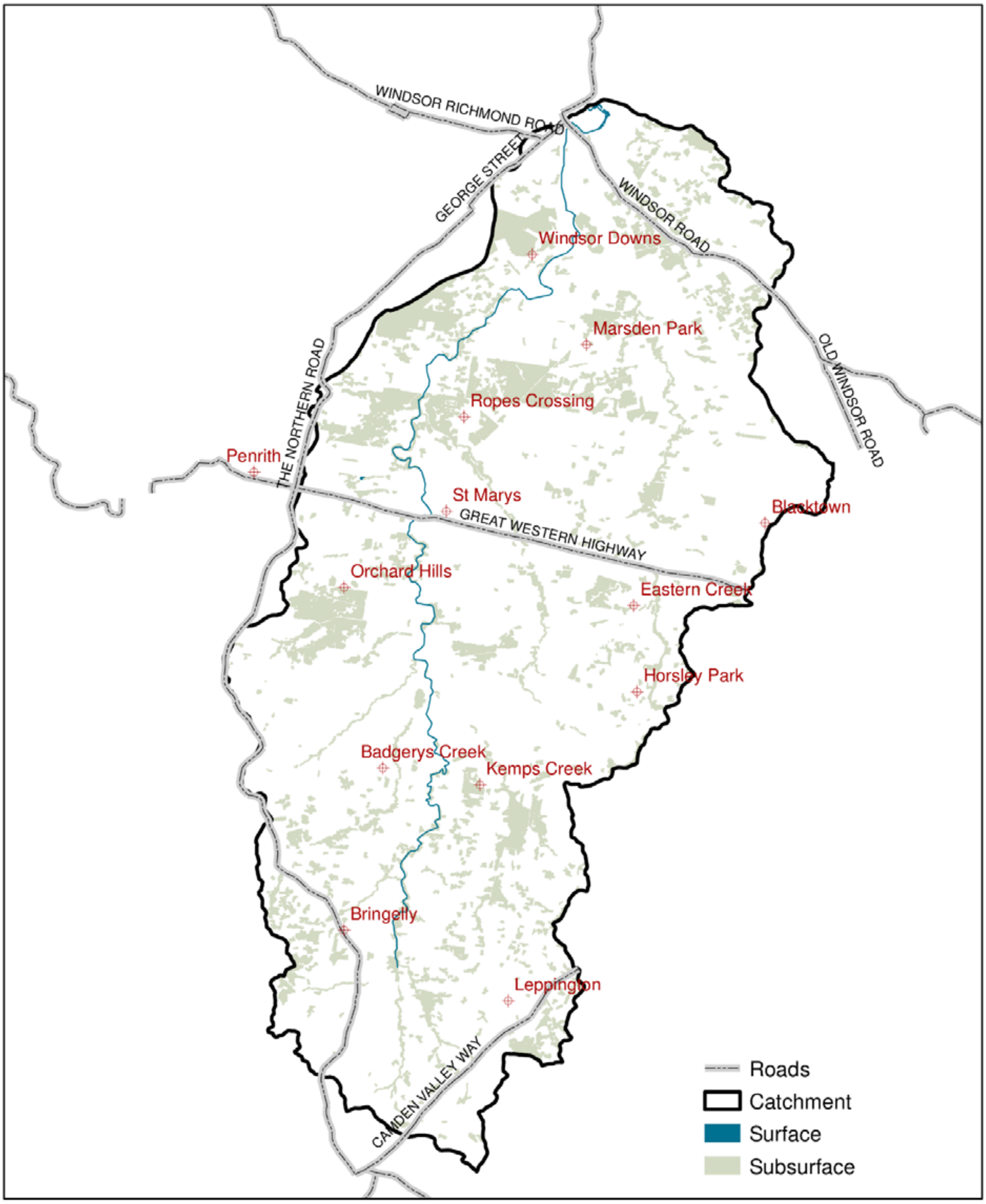

Figure 22 Groundwater dependent ecosystems

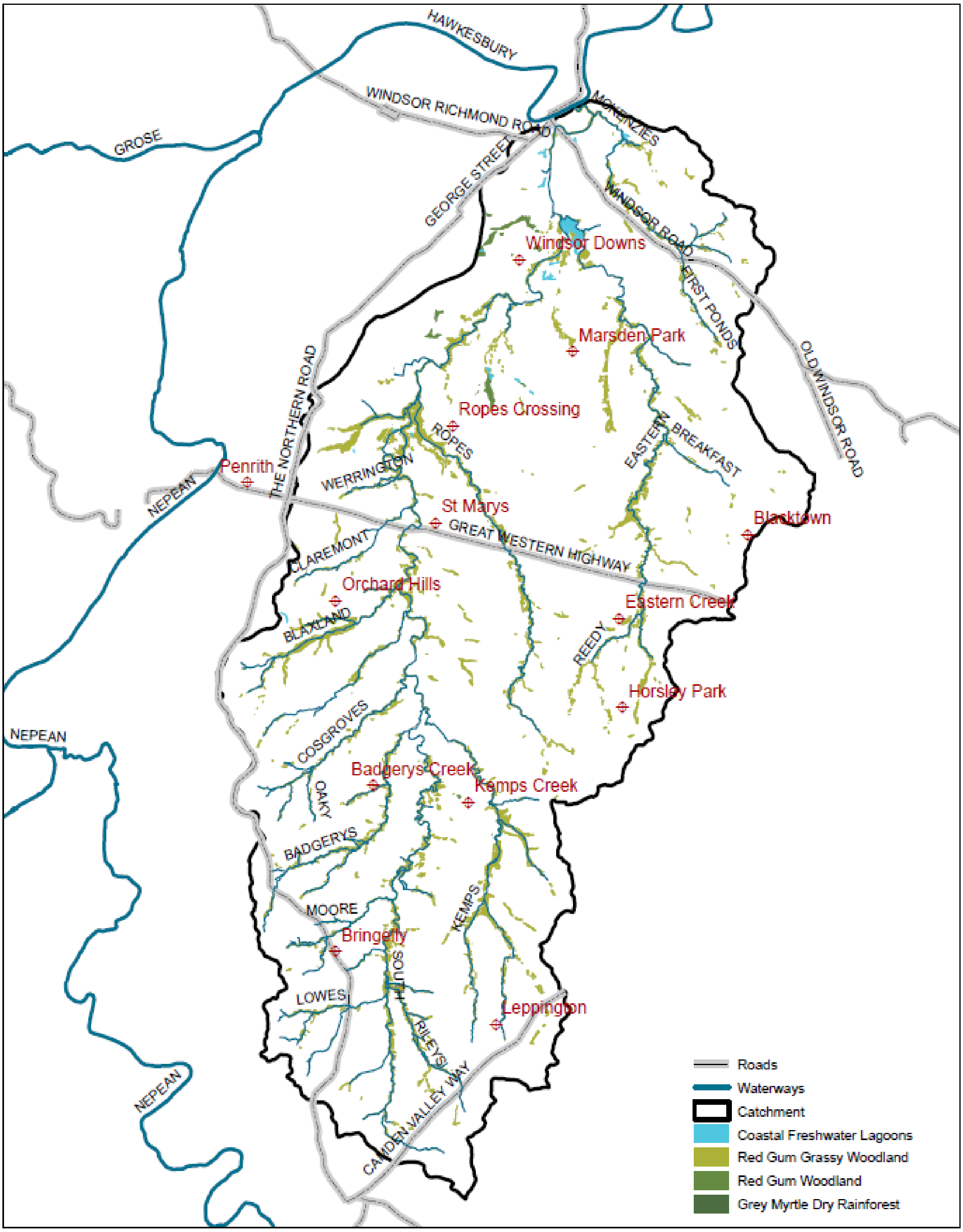

Figure 23 Endangered ecological communities

Refer to Appendix F, Table 7 for full description of PCT.

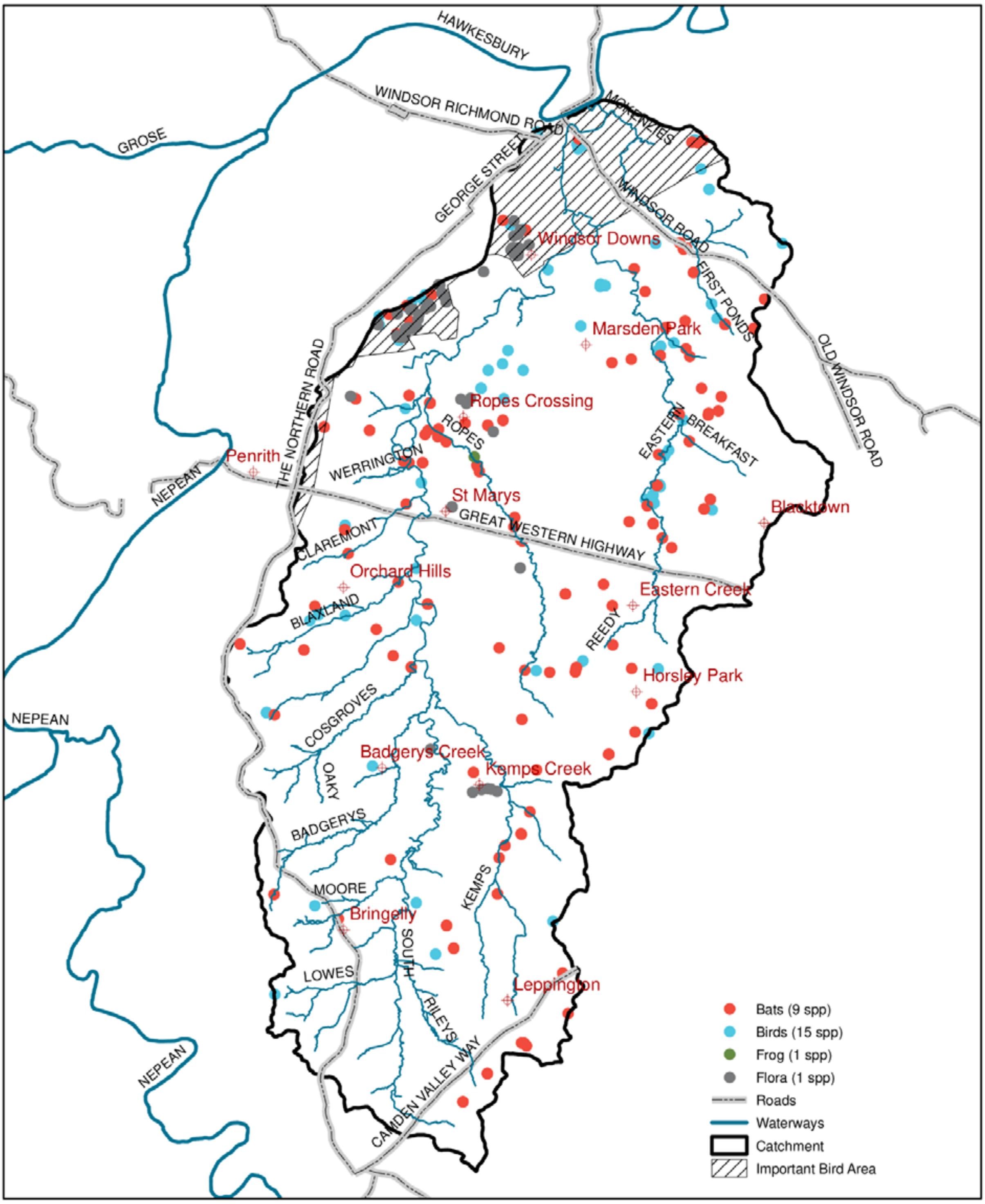

Figure 24 Important bird areas and species sightings

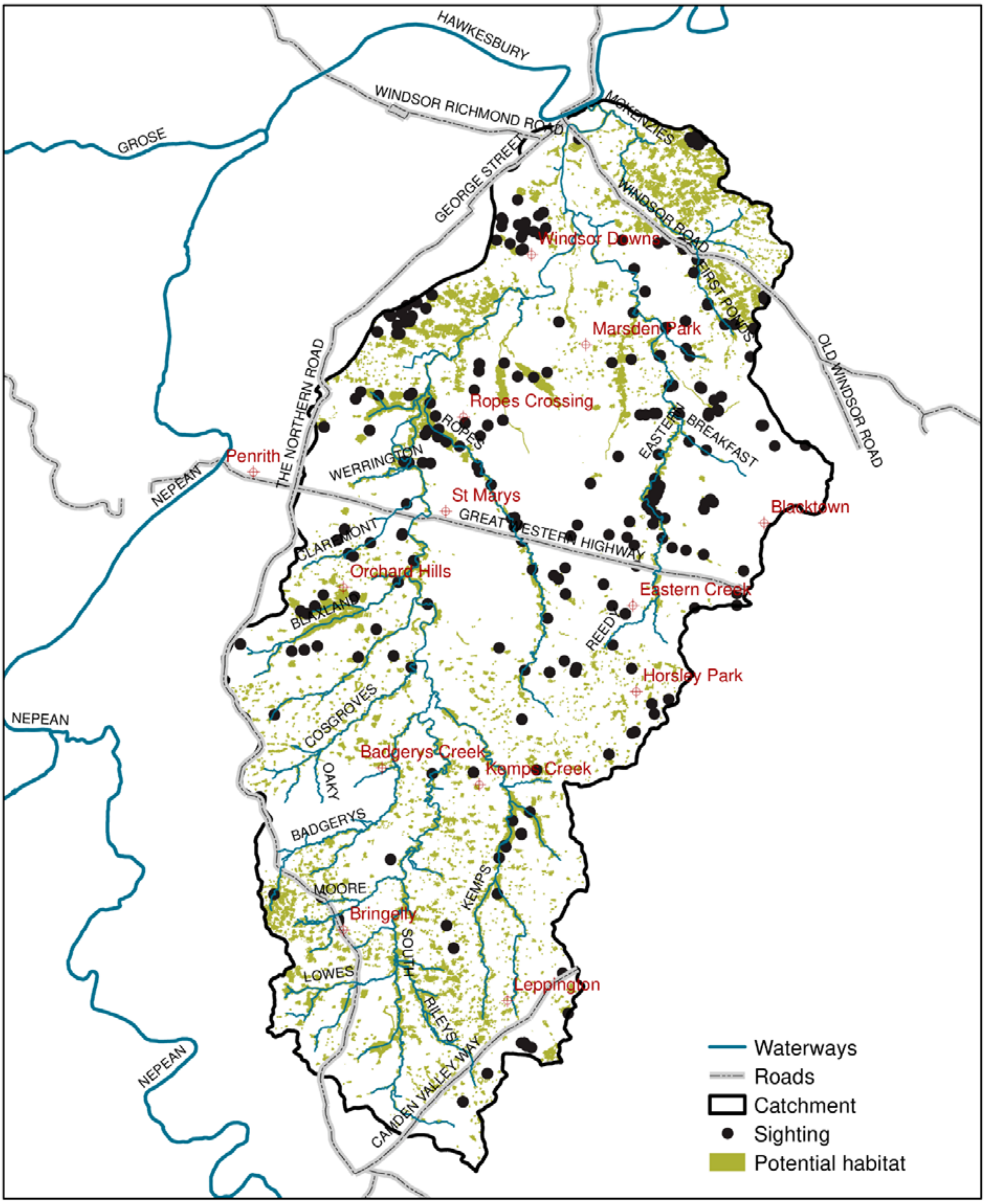

Figure 25 Water dependent flying-fox habitat and sightings

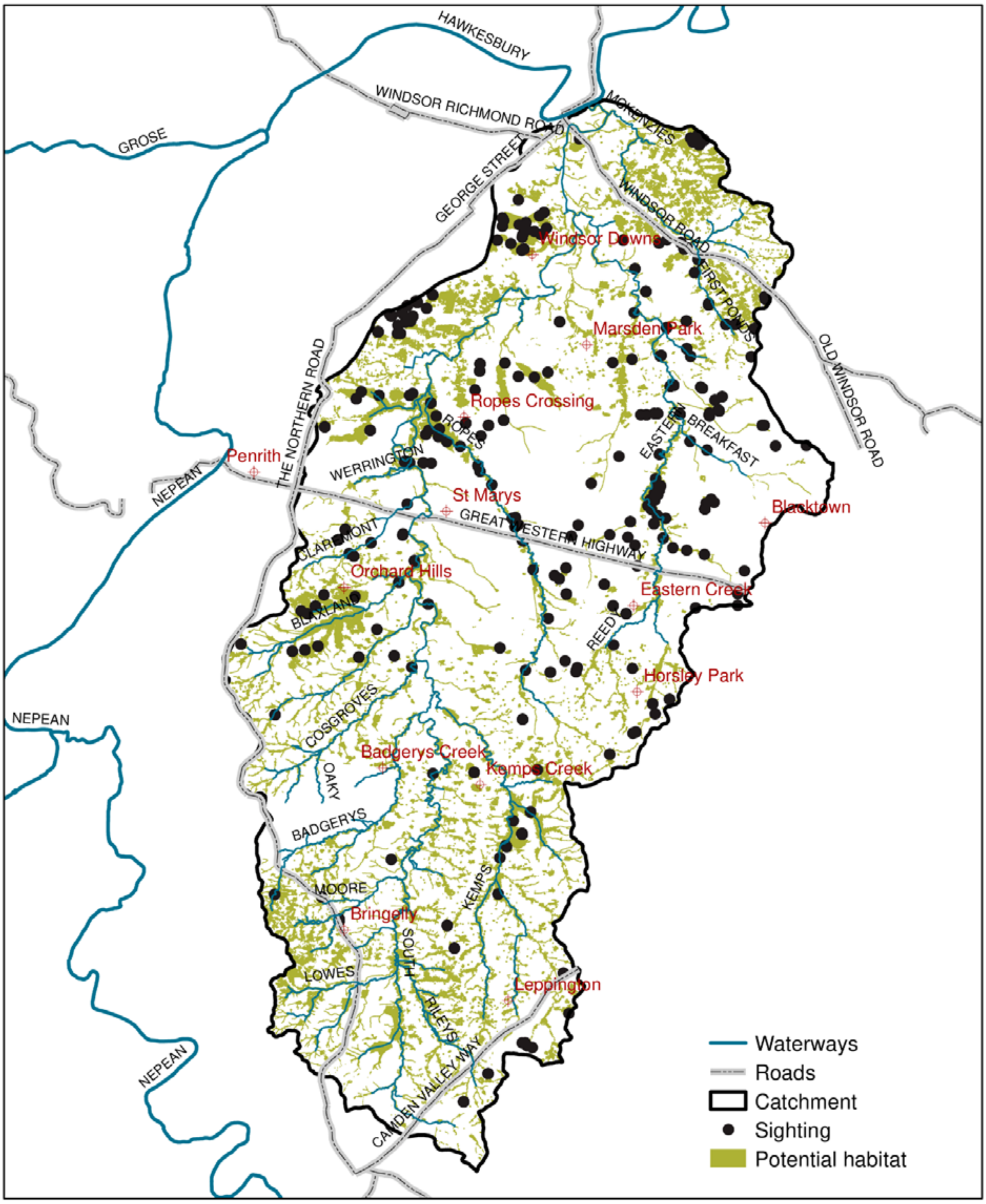

Figure 26 Water dependent microbat habitat and sightings

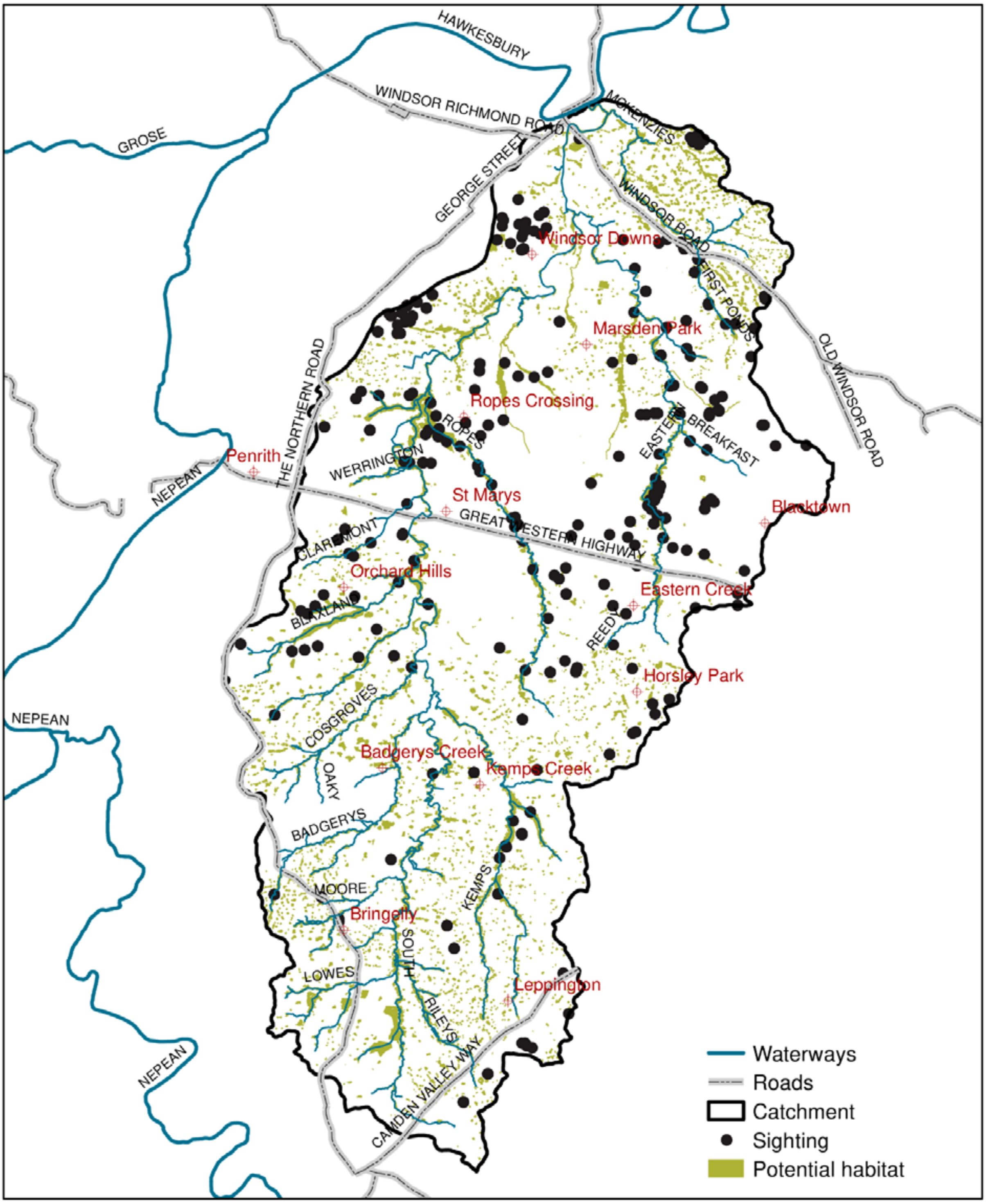

Figure 27 Water dependent Southern Myotis habitat and sightings

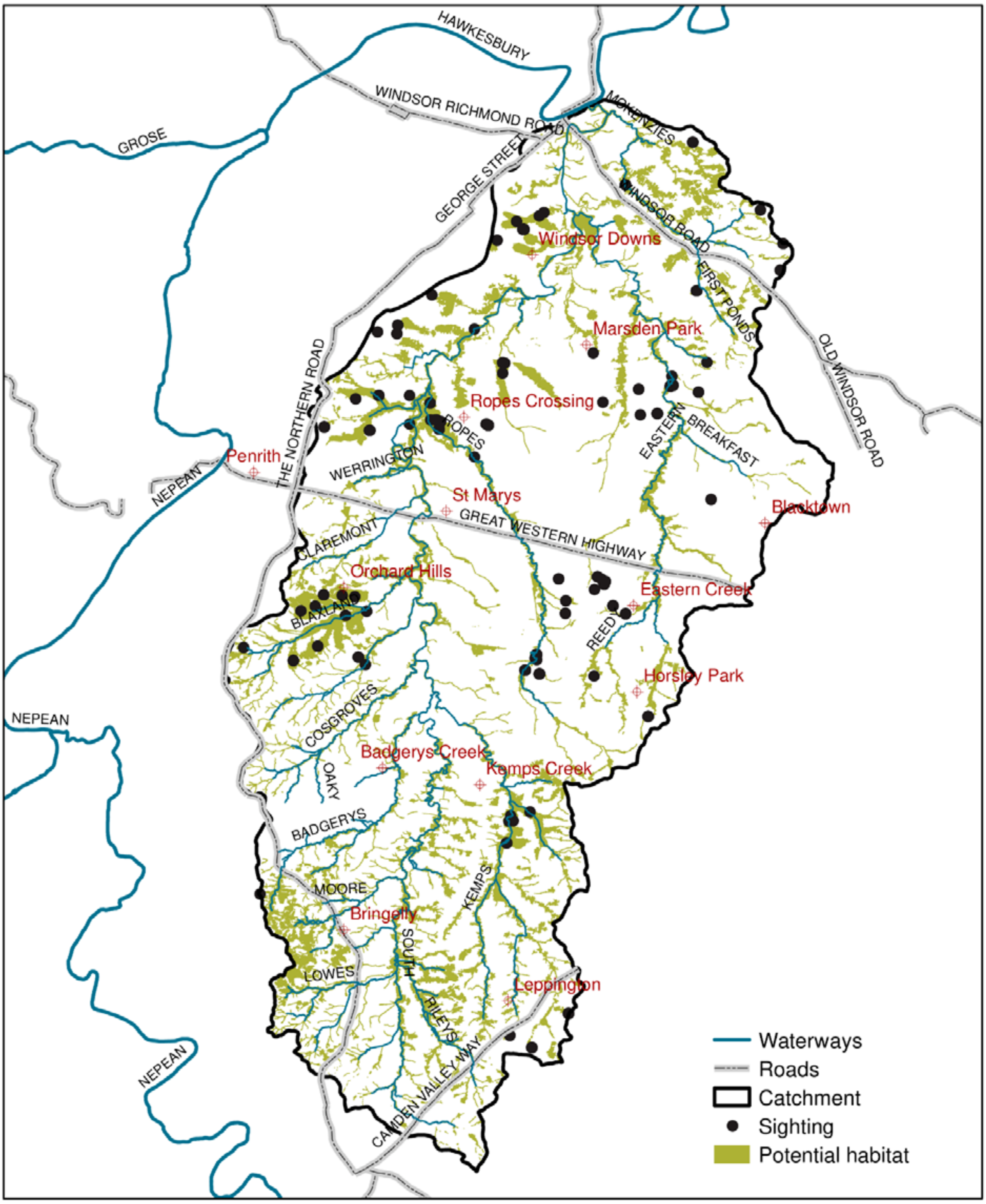

Figure 28 Tree frog habitat and sightings

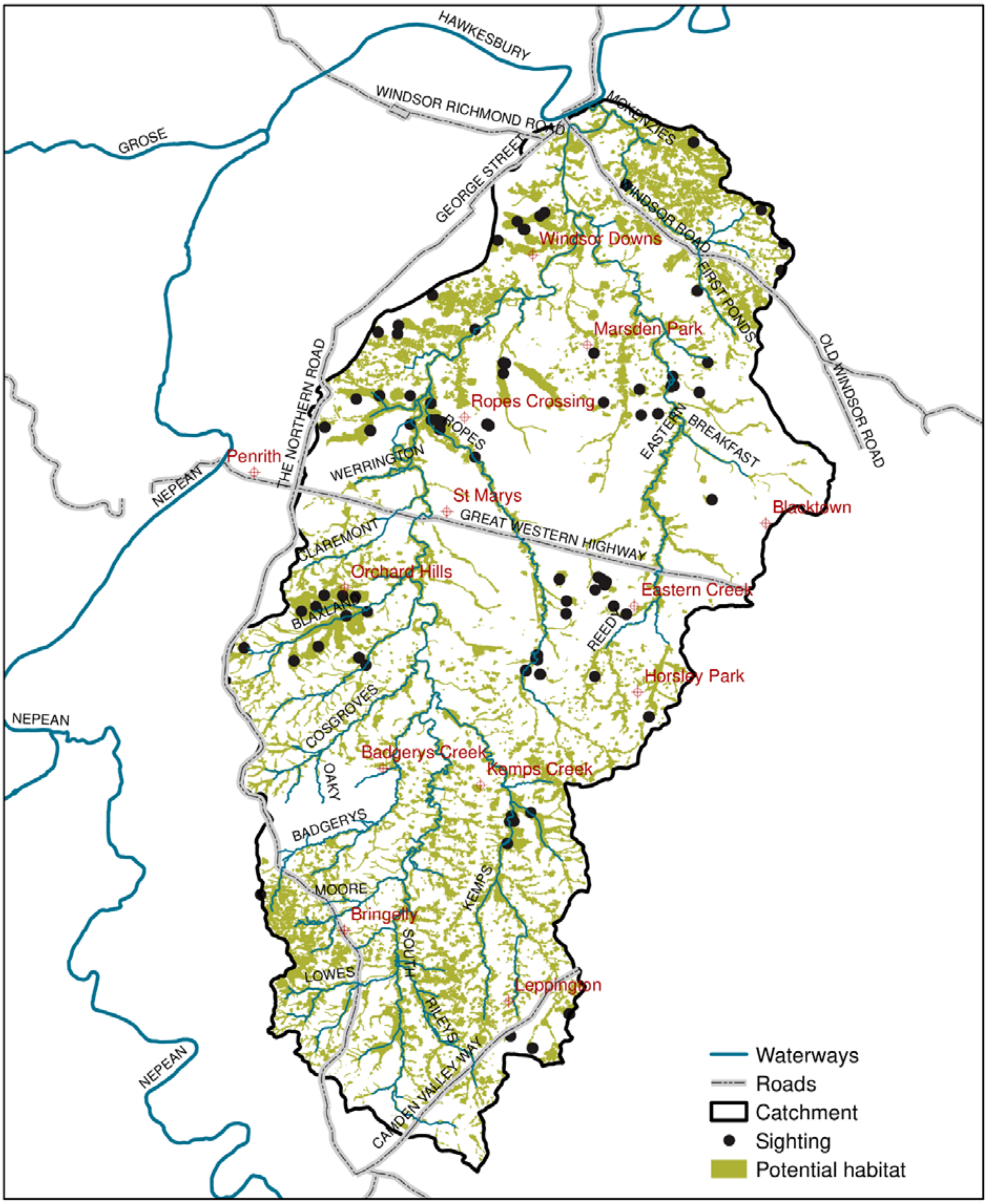

Figure 29 Ground and burrowing frog habitat and sightings

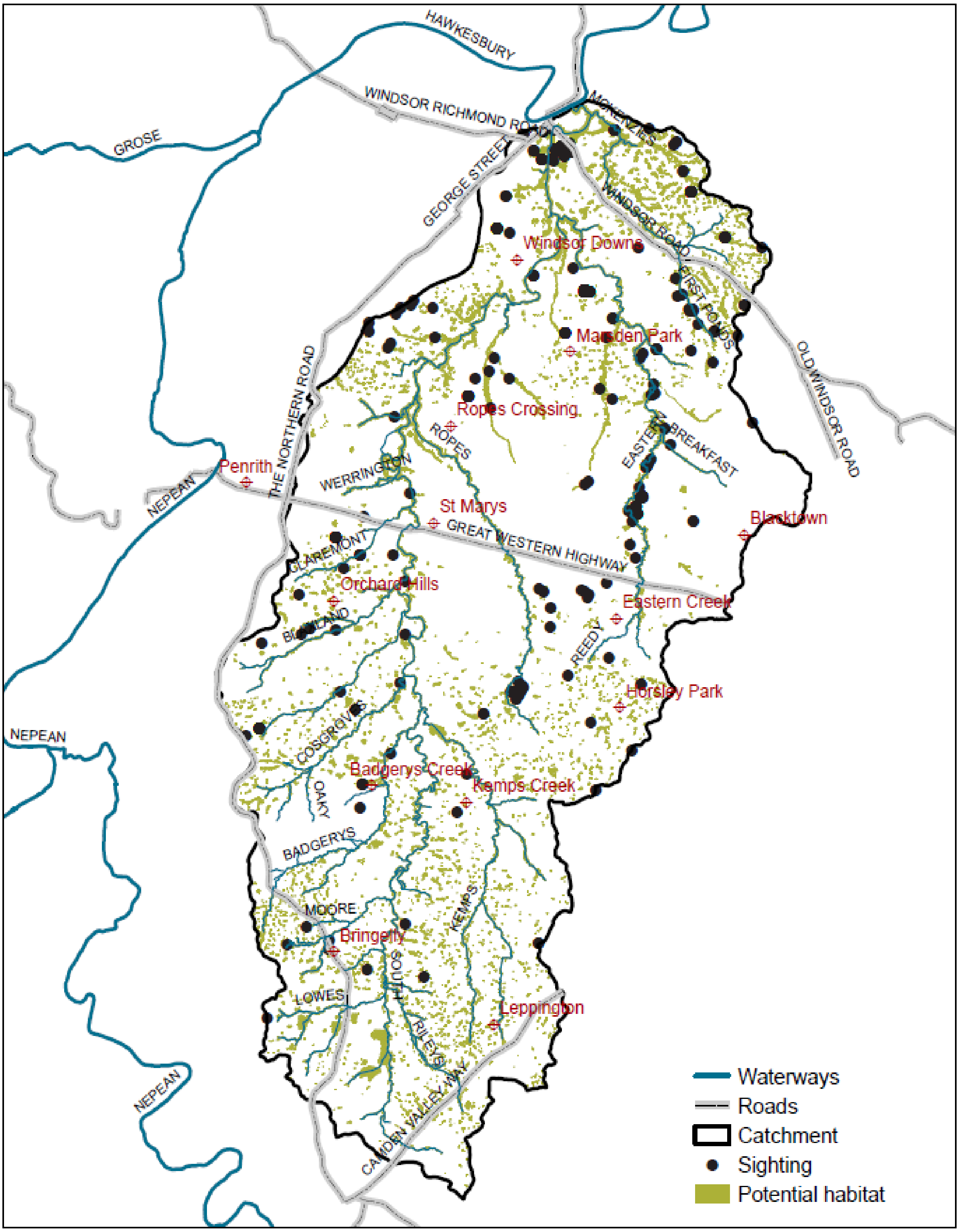

Figure 30 Large bird wader habitat and sightings

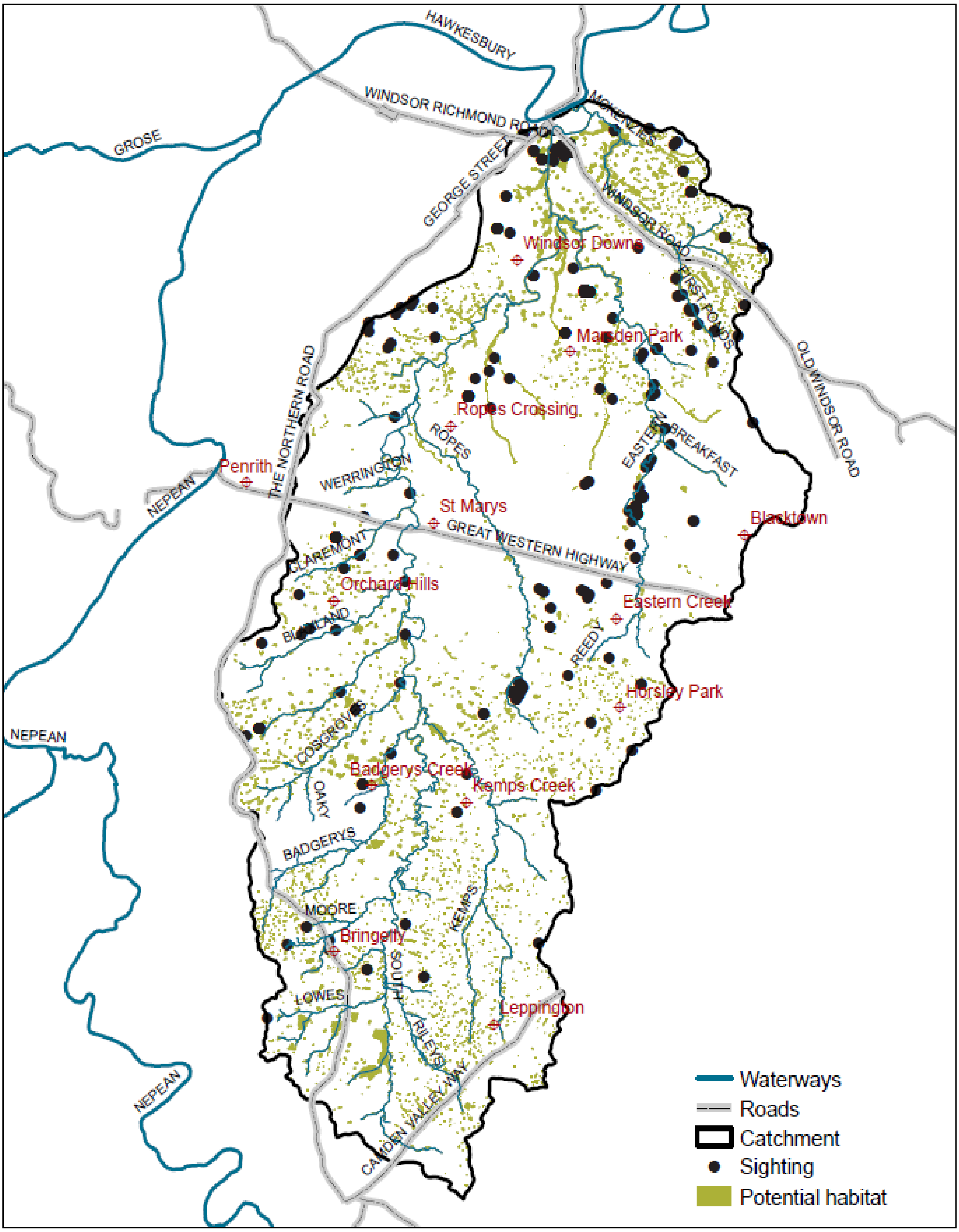

Figure 31 Small bird wader habitat and sightings

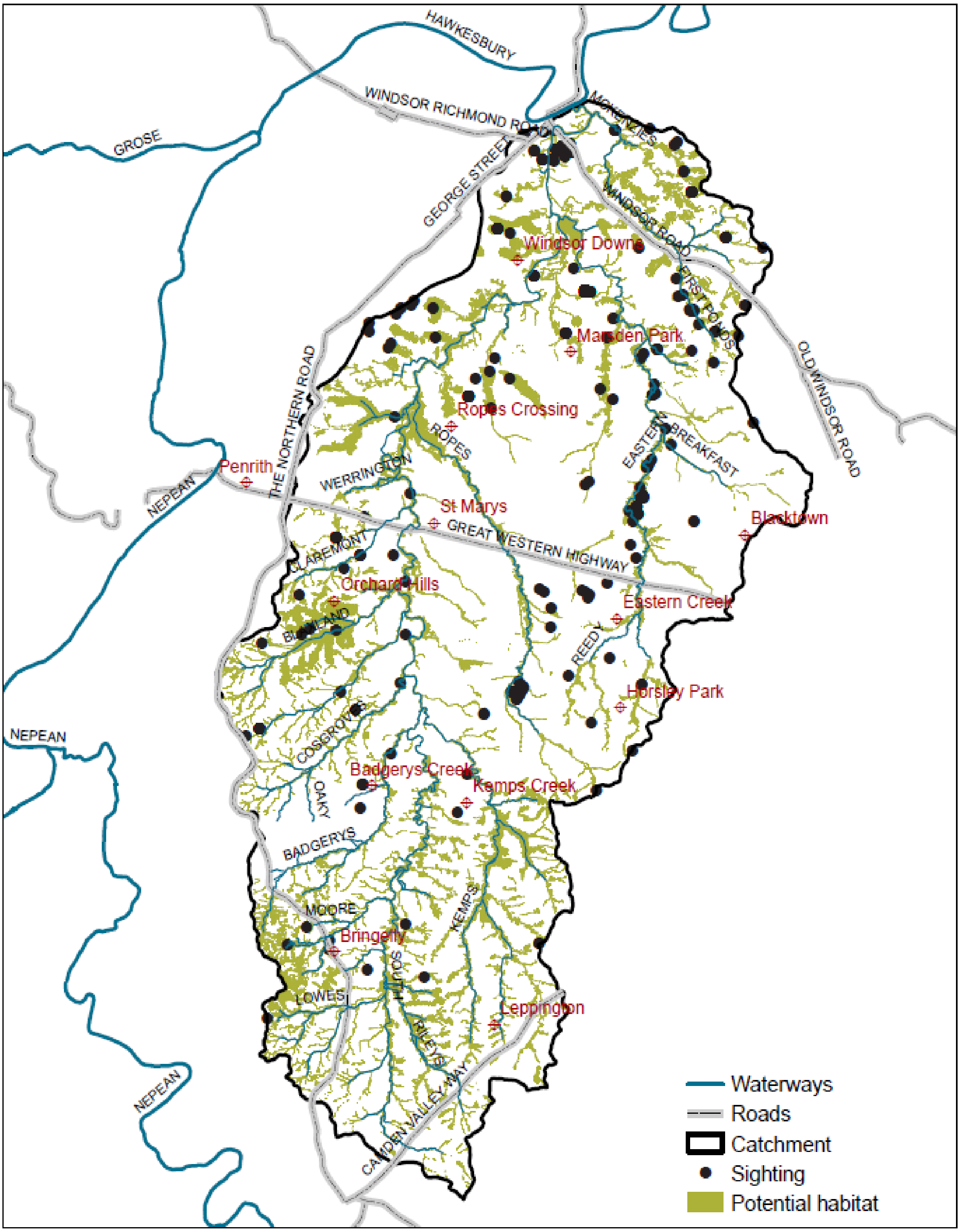

Figure 32 Riparian vegetation bird forager habitat and sightings

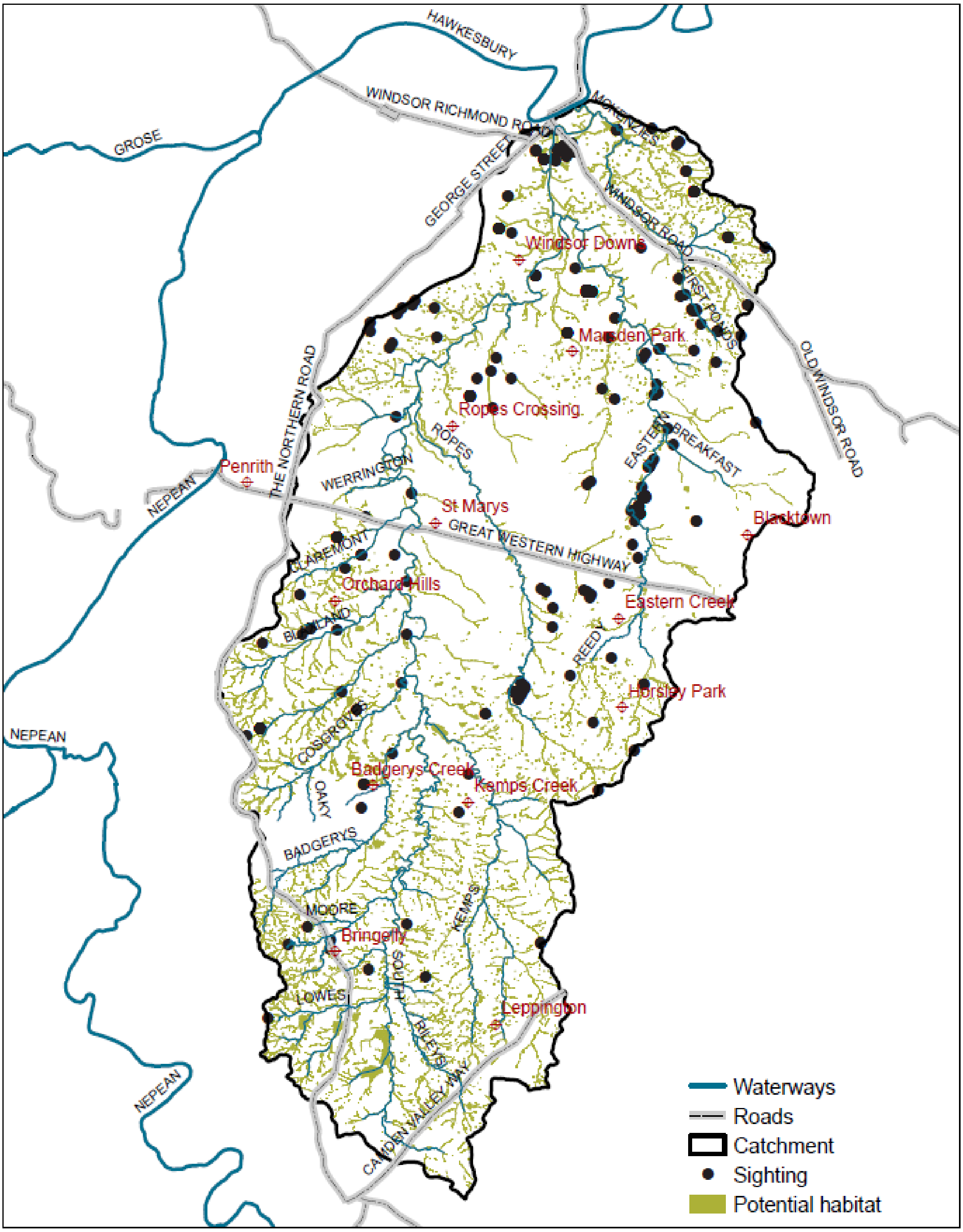

Figure 33 Open water bird foragers habitat and sightings

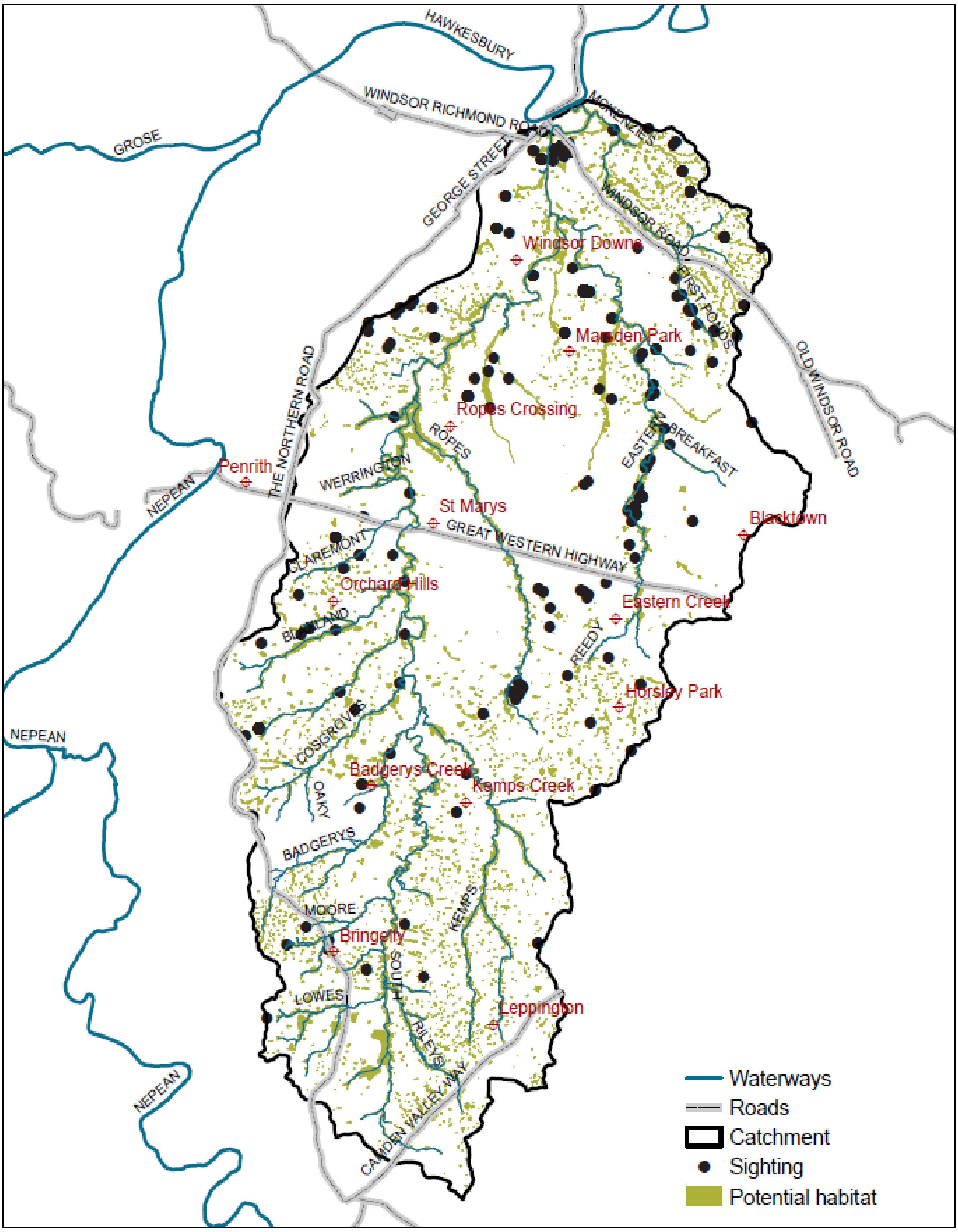

Figure 34 Emergent vegetation bird forager habitat and sightings

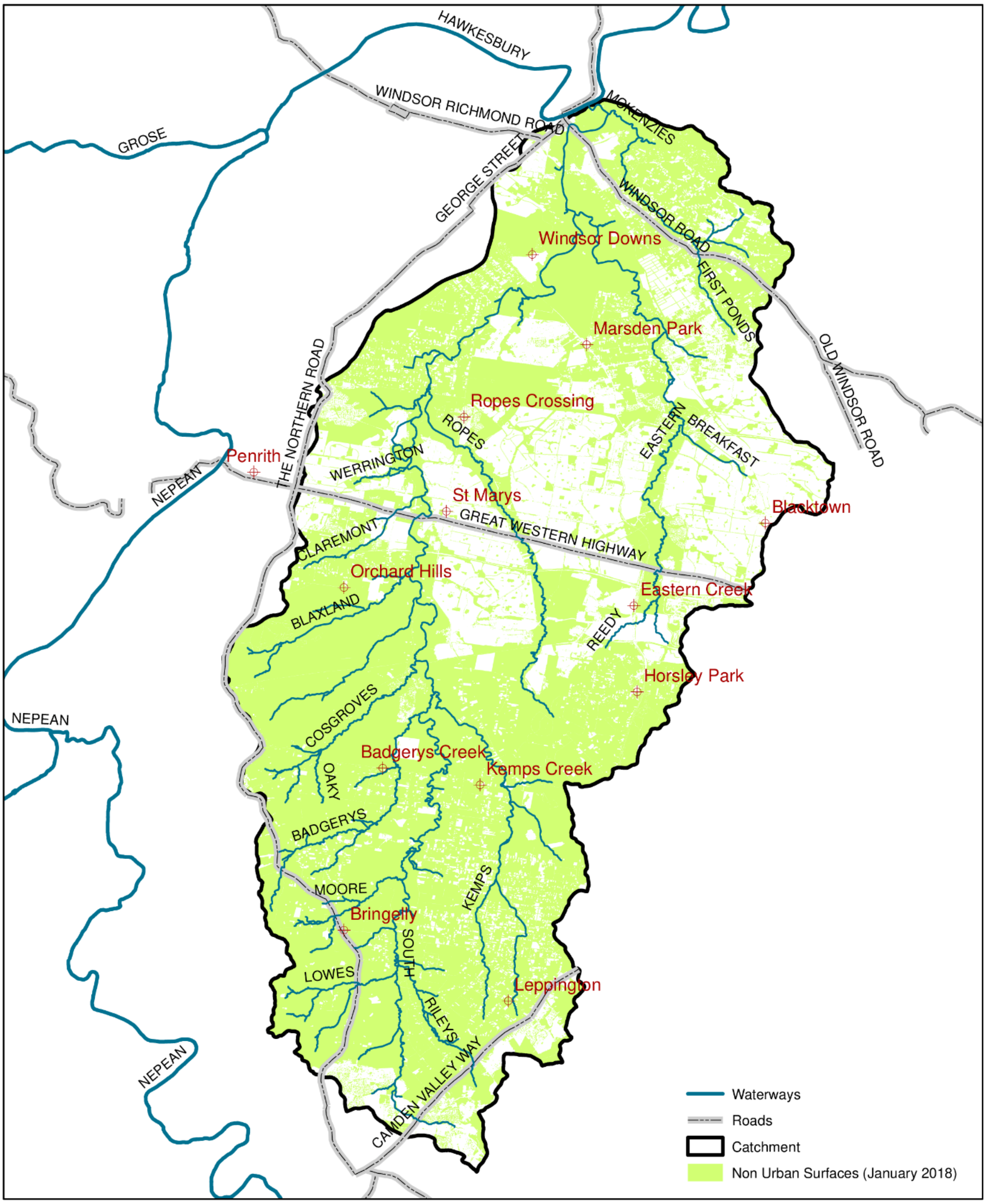

Figure 35 Non urban surfaces

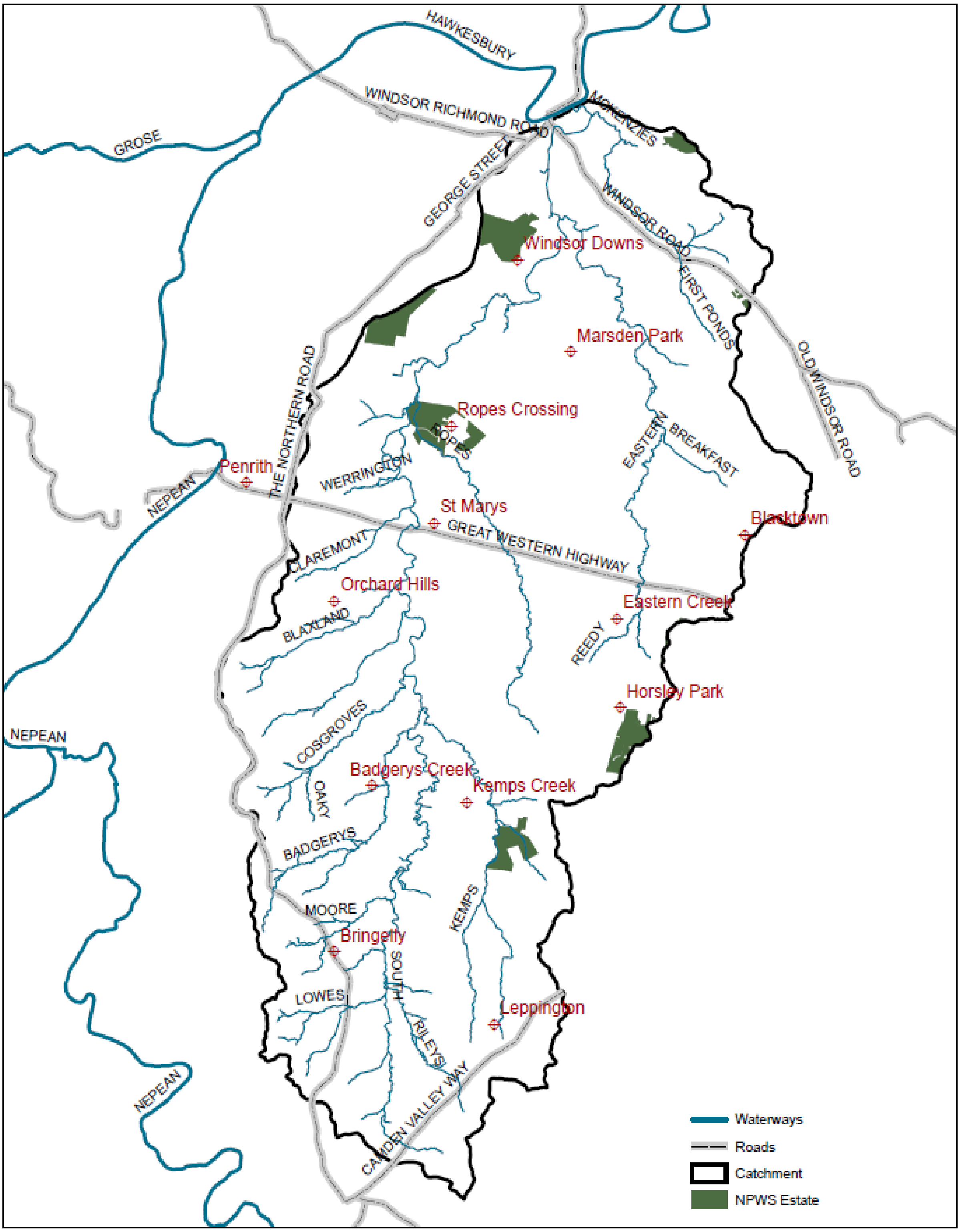

Figure 36 NPWS estate

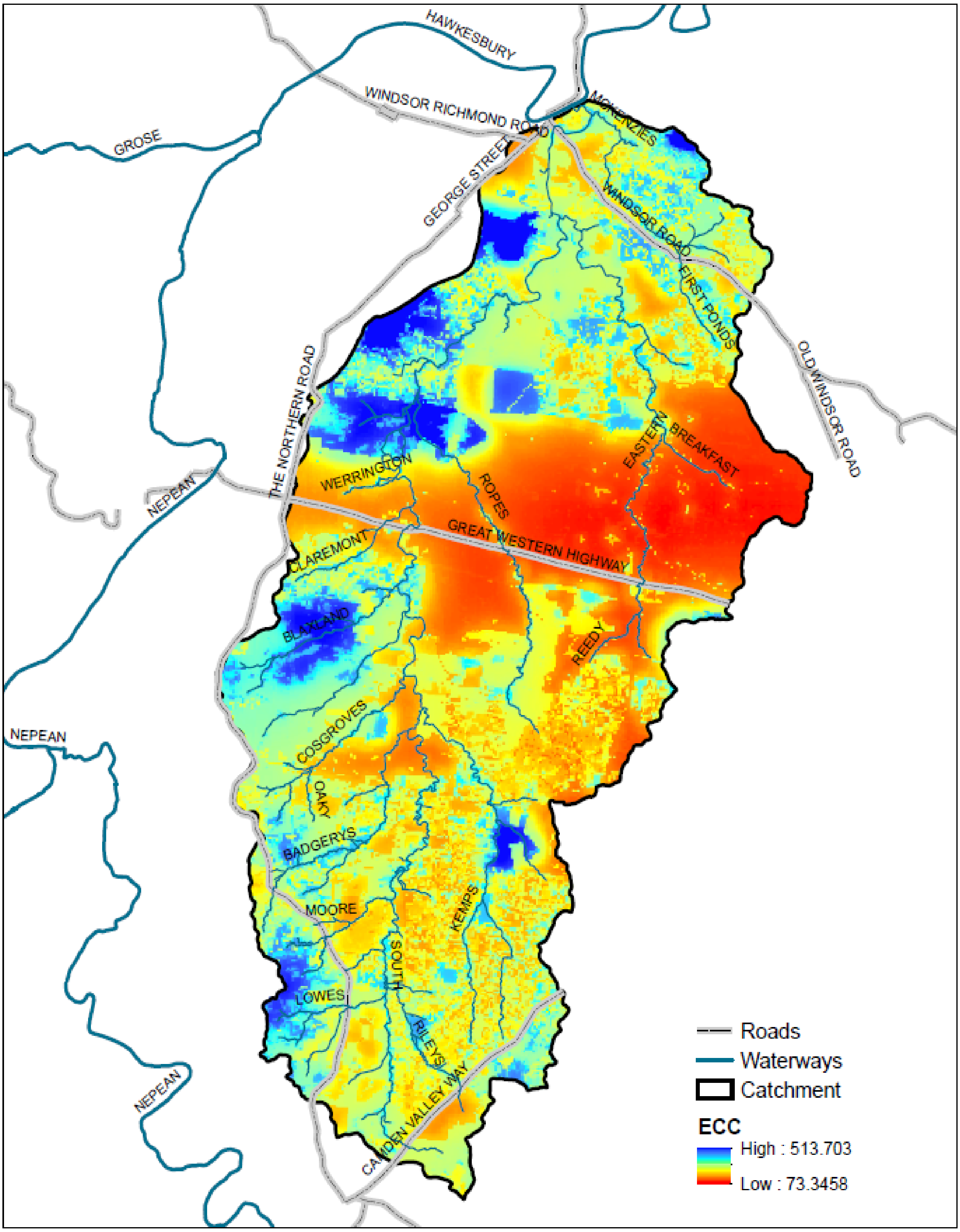

Figure 37 Ecological carrying capacity

Appendix F – Species lists, datasets and habitat requirements

Table 7 Relationship between the map attributes and units used among the various vegetation datasets available for developing the riparian vegetation (RIP) and wetlands (WET) maps shown in Figure 3 and Figure 4; surface water dependencies (SWT) and the final classification are shown

PCT[1]	Remnant vegetation map unit number[2,3]	NSW EEC[1,4,5,6]	EPBC[1]	Native vegetation[7]	RIP	WET	SWD	Final class
Broad-leaved Ironbark - Grey Box - Melaleuca decora grassy open forest on clay/gravel soils of the Cumberland Plain, Sydney Basin Bioregion	103 – Shale/Gravel Transition Forest	Shale Gravel Transition Forest in the Sydney Basin Bioregion	Shale Gravel Transition Forest in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation
Broad-leaved Ironbark - Melaleuca decora shrubby open forest on clay soils of the Cumberland Plain, Sydney Basin Bioregion	3 – Cooks River Castlereagh Ironbark Forest	Cooks River/ Castlereagh ironbark forest in the Sydney Basin Bioregion	Cooks River/ Castlereagh ironbark forest in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation
Coastal freshwater lagoons of the Sydney Basin Bioregion and South East Corner Bioregion	36 – Freshwater Wetlands	Freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Non-woody wetland			Y	Non-woody wetland
Forest Red Gum - Grey Box shrubby woodland on shale of the southern Cumberland Plain, Sydney Basin Bioregion	14 – Moist Shale Woodland	Moist Shale Woodland in the Sydney Basin Bioregion	Western Sydney Dry Rainforest and Moist Woodland on Shale	Dry sclerophyll				Other woody native vegetation
Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion	11 – Alluvial Woodland	River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Riparian forests (generic)	Y		Y	Riparian woodland

PCT[1]	Remnant vegetation map unit number[2,3]	NSW EEC[1,4,5,6]	EPBC[1]	Native vegetation[7]	RIP	WET	SWD	Final class
Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion	12 – Riparian Forest	River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Riparian forests (generic)	Y		Y	Riparian woodland
Grey Box - Forest Red Gum grassy woodland on flats of the Cumberland Plain, Sydney Basin Bioregion	10 – Shale Plains Woodland	Cumberland Plain Woodland in the Sydney Basin Bioregion	Cumberland Plain Woodland in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation
Grey Box - Forest Red Gum grassy woodland on shale of the southern Cumberland Plain, Sydney Basin Bioregion	9 – Shale Hills Woodland	Cumberland Plain Woodland in the Sydney Basin Bioregion	Cumberland Plain Woodland in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation
Grey Myrtle dry rainforest of the Sydney Basin Bioregion and South East Corner Bioregion	13 – Western Sydney Dry Rainforest	Western Sydney Dry Rainforest in the Sydney Basin Bioregion	Western Sydney Dry Rainforest in the Sydney Basin Bioregion	Dry rainforest				Other woody native vegetation
Hard-leaved Scribbly Gum - Parramatta Red Gum heathy woodland of the Cumberland Plain, Sydney Basin Bioregion	6 – Castlereagh Scribbly Gum Woodland	Castlereagh Scribbly Gum Woodland in the Sydney Basin Bioregion	Castlereagh Scribbly Gum Woodland in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation
Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, Sydney Basin Bioregion	4 – Castlereagh Swamp Woodland	Castlereagh Swamp Woodland	Not listed	Riparian forests (generic)		Y	Y	Woody wetland
Narrow-leaved Ironbark - Broad-leaved Ironbark - Grey Gum open forest of the edges of the Cumberland Plain, Sydney Basin Bioregion	1 – Shale Sandstone Transition Forest (Low Sandstone Influence)	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Dry sclerophyll				Other woody native vegetation

PCT[1]	Remnant vegetation map unit number[2,3]	NSW EEC[1,4,5,6]	EPBC[1]	Native vegetation[7]	RIP	WET	SWD	Final class
Narrow-leaved Ironbark - Broad-leaved Ironbark - Grey Gum open forest of the edges of the Cumberland Plain, Sydney Basin Bioregion	2 – Shale Sandstone Transition Forest (High Sandstone Influence)	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Dry				Other woody native vegetation
Swamp Oak open forest on riverflats of the Cumberland Plain and Hunter Valley	NOT MAPPED	Swamp Oak Floodplain Forest of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions / River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Swamp Oak Floodplain Forest of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions	Riparian forests (generic)	Y		y	Riparian woodland
Swamp Oak open forest on riverflats of the Cumberland Plain and Hunter Valley	NOT MAPPED	River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Riparian forests (generic)	Y		Y	Riparian woodland

1. NSW BioNet Vegetation Classification
2. Revised Remnant Vegetation of the western Cumberland subregion, 2013 update. VIS_ID 4207 (James 2018)
3. NPWS *Interpretation Guidelines for the Native Vegetation Maps of the Cumberland Plain, Western Sydney* (NPWS 2002)
4. Castlereagh Swamp Woodland Community profile
5. River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions profile
6. Freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions profile
7. NSW State Vegetation Type Map

Table 8 Water dependent species in the Wianamatta–South Creek catchment

Scientific name	Common name	Habitat group	NSW status	Commonwealth status	Habitat
Botaurus poiciloptilus	Australasian bittern	Emergent vegetation dependent birds	E2	E1	Freshwater wetlands with tall dense emergent vegetation
Ardea ibis	Cattle egret	Large wader birds		CAMBA, JAMBA	Shallow, open and fresh wetlands including grassy meadows and swamps
Ephippiorhynchus asiaticus	Black-necked stork	Large wader birds	E2		Swamps, billabongs, watercourses and lagoons on floodplains
Ixobrychus flavicollis	Black bittern	Large wader birds	V2		Areas of permanent water and dense vegetation
Plegadis falcinellus	Glossy ibis	Large wader birds		CAMBA	Freshwater marshes at the edges of lakes and rivers, lagoons, floodplains, wet meadows, swamps, reservoirs, sewage ponds
Haliaeetus leucogaster	White-bellied sea-eagle	Open water forager birds	V2	CAMBA	Perches and nests in trees, forages over waterways and adjacent land
Oxyura australis	Blue-billed duck	Open water forager birds	V2		Deep water in large permanent wetlands and swamps with dense aquatic vegetation
Calidris acuminata	Sharp-tailed sandpiper	Small wader birds		CAMBA, JAMBA, ROKAMBA	Prefers muddy edges of shallow fresh or brackish wetlands, with inundated or emergent sedges, grass, saltmarsh or other low vegetation
Calidris ferruginea	Curlew sandpiper	Small wader birds	E2	CE1, CAMBA, JAMBA, ROKAMBA	Prefers mudflats, including those around lagoons, lakes, dams, sewage ponds and floodwaters, and inundated shallow and/or vegetated floodplain wetlands including saltmarsh
Calidris melanotos	Pectoral sandpiper	Small wader birds		JAMBA, ROKAMBA	Prefers shallow fresh to saline wetlands, including lagoons, swamps, inundated grasslands, river pools, creeks, floodplains and artificial wetlands such as sewage ponds
Calidris ruficollis	Red-necked stint	Small wader birds		CAMBA, JAMBA, ROKAMBA	Prefers shallow fresh to saline wetlands, including lagoons, swamps, inundated grasslands, river pools, creeks, floodplains and artificial wetlands such as sewage ponds
Gallinago hardwickii	Latham's snipe	Small wader birds		CAMBA, JAMBA, ROKAMBA	Open shallow inundated well vegetated freshwater wetlands, including emergent sedges, grasses and other low vegetation

Scientific name	Common name	Habitat group	NSW status	Commonwealth status	Habitat
Pluvialis fulva	Pacific golden plover	Small wader birds		CAMBA, JAMBA, ROKAMBA	Prefers shallow fresh to saline wetlands, including lagoons, swamps, inundated grasslands, river pools, creeks, floodplains and artificial wetlands such as sewage ponds
Rostratula australis	Australian painted snipe	Small wader birds	E2	E1	Open shallow inundated well vegetated freshwater wetlands, including emergent sedges, grasses and other low vegetation
Tringa glareola	Wood sandpiper	Small wader birds		CAMBA, JAMBA, ROKAMBA	Well vegetated shallow, freshwater wetlands, and artificial wetlands. Prefers areas with wetland emergent and aquatic plants or grasses, with taller fringing vegetation
Tringa nebularia	Common greenshank	Small wader birds		CAMBA, JAMBA ROKAMBA	Prefers muddy edges of shallow fresh or brackish wetlands, with inundated or emergent sedges, grass, saltmarsh or other low vegetation
Tringa stagnatilis	Marsh sandpiper	Small wader birds		CAMBA, JAMBA, ROKAMBA	Prefers muddy edges of shallow fresh or brackish wetlands, with inundated or emergent sedges, grass, saltmarsh or other low vegetation
Stictonetta naevosa	Freckled duck	Wetland generalist* birds	V2		Freshwater swamps and creeks with dense vegetation over or adjacent to water
Climacteris picumnus	Brown treecreeper (eastern subspecies)	Riparian vegetation dependent birds	V2		Eucalypt forest bordering wetlands with an open understorey; fallen timber is for foraging
Anthochaera phrygia	Regent honeyeater	Riparian vegetation dependent birds	CE2	CE1	Inhabits open forests and woodland, including riparian forests of river sheoak
Apus pacificus	Fork-tailed swift	Riparian vegetation dependent birds		CAMBA, JAMBA, ROKAMBA	Inhabits a range of habitats including riparian woodland and tea-tree swamps
Artamus cyanopterus	Dusky woodswallow	Riparian vegetation dependent birds	V2		Inhabits a range of habitats including riparian woodland
Glossopsitta pusilla	Little lorikeet	Riparian vegetation dependent birds	V2		Forages in open eucalypt forest and woodland, particularly riparian forests
Lathamus discolor	Swift parrot	Riparian vegetation dependent birds	E2	CE1	Forages in eucalypt woodland and forests. Swamp mahogany is one of several favoured feeding trees
Melithreptus gularis	Black-chinned honeyeater (eastern subspecies)	Riparian vegetation dependent birds	V2		Inhabits open forests and woodlands; river sheoaks are used as nesting habitat

Scientific name	Common name	Habitat group	NSW status	Commonwealth status	Habitat
Merops ornatus	Rainbow bee-eater	Riparian vegetation dependent birds		JAMBA	Inhabits a range of forest and grassland habitats, including riparian, floodplain and wetland vegetation
Neophema pulchella	Turquoise parrot	Riparian vegetation dependent birds	V2		Eucalypt woodland, especially adjoining creeks
Petroica boodang	Scarlet robin	Riparian vegetation dependent birds	V2		Inhabits a range of habitats including wet forest, wetlands and tea-tree swamps
Stagonopleura guttata	Diamond firetail	Riparian vegetation dependent birds	V2		Inhabits a range of habitats, often found in riparian areas
Austronomus australis	White-striped freetail-bat	Microbats			Forages over woodland and forests. Roosts in tree-hollows, building ceilings
Chalinolobus dwyeri	Large-eared pied bat	Microbats	V2	V1	Forages over woodland and forests containing gullies. Roosts in tree hollows, caves, crevices in cliffs, old mine workings, and in disused bottle-shaped mud nests of the fairy martin
Chalinolobus gouldii	Gould's wattled bat	Microbats			Forages over forest, open woodland, open areas. Roosts in trees, and built structures (bridges, pipes, culverts, buildings)
Chalinolobus morio	Chocolate wattled bat	Microbats			Forages over forest, woodland and open grassland habitats. Forms colonies in tree hollows, caves, buildings
Falsistrellus tasmaniensis	Eastern false pipistrelle	Microbats	V2		Prefers moist habitats, with trees taller than 20 m. Roosts in eucalypt hollows, sometimes under loose bark or in buildings
Miniopterus australis	Little bentwing-bat	Microbats	V2		Forests and melaleuca swamps, especially densely vegetated habitats. Roosts in caves, tunnels, tree hollows, abandoned mines, stormwater drains, culverts, bridges, and sometimes buildings
Miniopterus schreibersii oceanensis	Eastern bentwing-bat	Microbats	V2		Forages in forested areas. Caves are the primary roosting habitat; may also use derelict mines, stormwater tunnels, buildings and other man-made structures
Mormopterus norfolkensis	Eastern freetail-bat	Microbats	V2		Dry sclerophyll forest, woodland, swamp forests. Mostly roosts in tree hollows, sometimes roosts under bark or in man-made structures

Scientific name	Common name	Habitat group	NSW status	Commonwealth status	Habitat
Mormopterus planiceps	Little mastiff-bat	Microbats			More common in wet habitats, but recorded from a range of habitats including forests and open woodland. Roosts in tree hollows, roof cavities, waterpipes, other man-made structures
Myotis macropus	Southern Myotis	Microbats	V2		Forages over streams and pools. Roosts close to water in caves, mine shafts, hollow bearing trees, stormwater channels, buildings, under bridges, and in dense vegetation
Nyctophilus geoffroyi	Lesser long-eared bat	Microbats			Forages in woodland, wet forest, and some urban areas. Roosts in tree hollows and crevices, under loose bark, in roofs of houses
Nyctophilus gouldi	Gould's long-eared bat	Microbats			Forages in sclerophyll forest and woodland. Roosts in tree hollows, under roofs
Pteropus alecto	Black flying-fox	Flying-foxes			Feeds on rainforest fruits, and nectar and pollen from eucalypts, paperbarks and banksias. Roosts in subtropical rainforest or swamp forest
Pteropus poliocephalus	Grey-headed flying-fox	Flying-foxes	V2	V1	Subtropical and temperate rainforests, tall sclerophyll forests, woodlands and swamps, urban gardens and orchards. Roosting camps are commonly in gullies, close to water, with a dense vegetation canopy
Rhinolophus megaphyllus	Eastern horseshoe-bat	Microbats			Forages in closed forest habitats, and sometimes in drier vegetation types, rural gardens and plantations. Roosts in caves and underground structures.
Saccolaimus flaviventris	Yellow-bellied sheathtail-bat	Microbats	V2		Forages in forest, woodland, and grassland/pasture. Roosts in tree hollows and buildings, sometimes uses mammal burrows
Scoteanax rueppellii	Greater broad-nosed bat	Microbats	V2		Forages along creek and river corridors, in open woodland and forests. Roosting habitat is poorly studied, thought to roost in tree hollows and crevices and under loose bark
Scotorepens orion	Eastern broad-nosed bat	Microbats			Mostly forages in tall, wet forests or rainforest, sometimes in areas of open woodland. Roosts in tree hollows and roofs
Vespadelus darlingtoni	Large forest bat	Microbats			Forages in forests, farmland, and urban areas. Roosts in tree hollows and sometimes in buildings
Vespadelus pumilus	Eastern forest bat	Microbats			Forages in moist forests. Roosts in tree hollows

Scientific name	Common name	Habitat group	NSW status	Commonwealth status	Habitat
Vespadelus regulus	Southern forest bat	Microbats			Forages in woodlands, forests, farmland, and urban areas. Roosts in tree hollows and buildings
Vespadelus vulturnus	Little forest bat	Microbats			Forages in woodlands, dry and wet sclerophyll forest
Heleioporus australiacus	Giant burrowing frog	Burrowing frogs	V2	V1	Breeding: pools along 1st and 2nd order streams, and rain filled depressions. Shelter: sandy and loamy soils with native vegetation cover
Limnodynastes dumerilii	Eastern banjo frog	Burrowing frogs			Breeding: stream pools, permanent dams and ponds, rocks and native vegetation adjacent to pools. Shelter: loamy soils in areas of native vegetation for burrowing
Platyplectrum ornatum	Ornate burrowing frog	Burrowing frogs			Breeding: ephemeral pools, puddles, flooded grassland, ditches surrounded by native vegetation. Shelter: burrow during the day and through dry periods along dry sandy watercourses
Crinia parinsignifera	Eastern sign-bearing froglet	Ground frogs			Breeding: ephemeral and permanent pools, grassy vegetation around pools, submerged vegetation. Shelter habitat: logs, plant debris, rocks, in moist depressions
Crinia signifera	Common eastern froglet	Ground frogs			Breeding: ephemeral and permanent pools, surrounded with grassy vegetation. Shelter: logs, plant debris, and rocks, in moist depressions
Limnodynastes peronii	Brown-striped frog	Ground frogs			Breeding: ephemeral and permanent pools with flooded or emergent vegetation, surrounded by vegetation, plant debris, rock ledges. Shelter: native vegetation, sandy and loamy soils
Limnodynastes tasmaniensis	Spotted grass frog	Ground frogs			Breeding: ephemeral or permanent pools with flooded or emergent vegetation. Shelter: vegetation in and around pools, logs, rocks, plant debris
Litoria aurea	Green and golden bell frog	Ground frogs	E2	V1	Breeding: shallow ephemeral and permanent pools, with emergent and submerged vegetation, surrounded by tussock grasses or other low dense vegetation. Shelter: piles of rocks, dense tussock vegetation, emergent vegetation, fissures or cracks in ground, logs

Scientific name	Common name	Habitat group	NSW status	Commonwealth status	Habitat
Paracrinia haswelli	Haswell's froglet	Ground frogs			Breeding: permanent and semi-permanent pools, surrounded by leaf litter, vegetation. Shelter: Vegetation alongside creeks, rocks in creek beds
Pseudophryne bibronii	Bibron's toadlet	Ground frogs			Breeding: permanent and semi-permanent pools, flooded vegetation. Breeding occurs at moist sites under rocks, logs, leaf litter, grass clumps, or in a short tunnel in damp soil. Eggs are then washed into pools by rainfall. Shelter: under leaf litter and plant debris in moist soaks and depressions
Uperoleia fusca	Dusky toadlet	Ground frogs			Breeding: ephemeral and permanent pools, with submerged plant material, and surrounded by grasses or other vegetation. Shelter: forests with a grassy understorey, sedges and grasses
Uperoleia laevigata	Smooth toadlet	Ground frogs			Breeding: ephemeral and permanent pools, with submerged plant material, and surrounded with grassy vegetation. Shelter: grassland and woodland vegetation
Litoria caerulea	Green tree frog	Tree frogs			Breeding: ephemeral pools. Shelter: trees, hollow tree trunks, crevices in rocks
Litoria dentata	Bleating tree frog	Tree frogs			Breeding: ephemeral pools surrounded by vegetation. Shelter: rocks and loose bark on trees
Litoria ewingii	Brown tree frog	Tree frogs			Breeding: ephemeral and permanent pools, with submerged plant material or emergent plants, and surrounded by vegetation. Shelter: tree hollows, under bark
Litoria fallax	Eastern dwarf tree frog	Tree frogs			Breeding: ephemeral and permanent pools, especially those with emergent reeds. Shelter: leaf axils, emergent vegetation, trees
Litoria latopalmata	Broad-palmed frog	Tree frogs			Breeding: ephemeral and permanent pools, and shallow still water along streams and rivers. Shelter: forests, woodland, grassland, pastures
Litoria peronii	Peron's tree frog	Tree frogs			Breeding: permanent waterbodies, swamps, pools along creeks, with adjacent or overhanging vegetation, leaf litter. Shelter: trees and shrubs

Scientific name	Common name	Habitat group	NSW status	Commonwealth status	Habitat
Litoria phyllochroa	Leaf-green tree frog	Tree frogs			Breeding: creek pools and ponds, rocky streams, with surrounding or overhanging ferns or leafy vegetation. Shelter: shrubs and low vegetation beside creeks and ponds
Litoria tyleri	Tyler's tree frog	Tree frogs			Breeding: permanent waterbodies and ponds, with surrounding shrubs or trees. Shelter: trees and other vegetation overhanging ponds
Litoria verreauxii	Verreaux's frog	Tree frogs			Breeding: permanent waterbodies with submerged plant material, and surrounding low or emergent vegetation. Shelter: leaf litter, logs, beneath rocks, trees

Table 9 Species sighting dataset for water dependent threatened and migratory birds between January 1995 and December 2017

The valid records were determined by subject matter experts, and the quality checked records reflect the total number of records remaining after accounting for recent urban developments and spatial accuracy within a 10 m radius.

Scientific name	Common name	Habitat group	Valid records	Quality checked records	Final
Botaurus poiciloptilus	Australasian bittern	Emergent vegetation dependent large wader*	3	1	142
Stictonetta naevosa	Freckled duck	Wetland generalist*	2	1	
Ardea ibis	Cattle egret	Large wader	115	101	
Ephippiorhynchus asiaticus	Black-necked stork	Large wader	1	1	
Ixobrychus flavicollis	Black bittern	Large wader	21	16	
Plegadis falcinellus	Glossy ibis	Large wader	27	23	
Haliaeetus leucogaster	White-bellied sea-eagle	Open water forager	63	22	23
Oxyura australis	Blue-billed duck	Open water forager	2	1	
Anthochaera phrygia	Regent honeyeater	Riparian vegetation dependent	14	14	171
Apus pacificus	Fork-tailed swift	Riparian vegetation dependent	4	2	
Artamus cyanopterus	Dusky woodswallow	Riparian vegetation dependent	124	98	
Climacteris picumnus vitoriae	Brown treecreeper (eastern subspecies)	Riparian vegetation dependent	4	4	
Glossopsitta pusilla	Little lorikeet	Riparian vegetation dependent	11	10	
Lathamus discolor	Swift parrot	Riparian vegetation dependent	97	8	
Melithreptus gularis	Black-chinned honeyeater (eastern subspecies)	Riparian vegetation dependent	26	12	
Merops ornatus	Rainbow bee-eater	Riparian vegetation dependent	14	5	
Neophema pulchella	Turquoise parrot	Riparian vegetation dependent	5	2	
Petroica boodang	Scarlet robin	Riparian vegetation dependent	16	10	
Stagonopleura guttata	Diamond firetail	Riparian vegetation dependent	8	6	
Calidris acuminata	Sharp-tailed sandpiper	Small wader	69	59	158
Calidris ferruginea	Curlew sandpiper	Small wader	4	4	
Calidris melanotos	Pectoral sandpiper	Small wader	11	11	
Calidris ruficollis	Red-necked stint	Small wader	15	13	
Gallinago hardwickii	Latham’s snipe	Small wader	60	30	
Pluvialis fulva	Pacific golden plover	Small wader	14	9	

Scientific name	Common name	Habitat group	Valid records	Quality checked records	Final
Rostratula australis	Australian painted snipe	Small wader	11	6	
Tringa glareola	Wood sandpiper	Small wader	14	12	
Tringa nebularia	Common greenshank	Small wader	4	3	
Tringa stagnatilis	Marsh sandpiper	Small wader	11	11	

*Records for emergent vegetation dependent and wetland generalist birds were combined with the large wader birds to produce a single species distribution model.

Table 10 Species sighting dataset for frogs between January 1995 and December 2017

The valid records were determined by subject matter experts, and the quality checked records reflect the total number of records remaining after accounting for recent urban developments and spatial accuracy within a 10 m radius.

Scientific name	Common name	Habitat group	Valid records	Quality checked records	Final
Litoria caerulea	Green tree frog	Tree frog	32	5	117
Litoria dentata	Bleating tree frog	Tree frog	24	6	
Litoria ewingii	Brown tree frog	Tree frog	1	0	
Litoria fallax	Eastern dwarf tree frog	Tree frog	97	35	
Litoria peronii	Peron's tree frog	Tree frog	88	39	
Litoria phyllochroa	Leaf-green tree frog	Tree frog	3	0	
Litoria tyleri	Tyler's tree frog	Tree frog	7	2	
Litoria verreauxii	Verreaux's frog	Tree frog	77	30	
Crinia parinsignifera	Eastern sign-bearing froglet	Ground frog	1	0	148
Crinia signifera	Common eastern froglet	Ground frog	248	82	
Limnodynastes peronii	Brown-striped frog	Ground frog	96	26	
Limnodynastes tasmaniensis	Spotted grass frog	Ground frog	59	16	
Litoria aurea	Green and golden bell frog	Ground frog	9	1	
Litoria latopalmata	Broad-palmed frog	Ground frog	14	1	
Paracrinia haswelli	Haswell's froglet	Ground frog	1	0	
Pseudophryne bibronii	Bibron's toadlet	Ground frog	9	0	
Uperoleia fusca	Dusky toadlet	Ground frog	2	0	
Uperoleia laevigata	Smooth toadlet	Ground frog	47	19	
Heleioporus australiacus	Giant burrowing frog	Burrowing frog	1	0	
Limnodynastes dumerilii	Eastern banjo frog	Burrowing frog	13	3	
Platyplectrum ornatum	Ornate burrowing frog	Burrowing frog	3	0	

Table 11 Species sighting dataset for water dependent bats between January 2000 and April 2018

The valid records were determined by subject matter experts, and the quality checked records reflect the total number of records remaining after accounting for recent urban developments and spatial accuracy within a 10 m radius.

Scientific name	Common name	Habitat group	Valid records	Quality checked records	Final
Microbat, species not identified	Microbat, species not identified	Microbat	65	62	938
Austronomus australis	White-striped freetail-bat	Microbat	67	62	
Chalinolobus dwyeri	Large-eared pied bat	Microbat	6	6	
Chalinolobus gouldii	Gould's wattled bat	Microbat	212	191	
Chalinolobus morio	Chocolate wattled bat	Microbat	78	74	
Falsistrellus tasmaniensis	Eastern false pipistrelle	Microbat	19	17	
Miniopterus australis	Little bentwing-bat	Microbat	6	6	
Miniopterus schreibersii oceanensis	Eastern bentwing-bat	Microbat	67	60	
Mormopterus norfolkensis	Eastern freetail-bat	Microbat	57	52	
Mormopterus planiceps	Little mastiff-bat	Microbat	11	11	
Myotis macropus	Southern myotis	Microbat	48	41	
Nyctophilus geoffroyi	Lesser long-eared bat	Microbat	98	98	
Nyctophilus gouldi	Gould's long-eared bat	Microbat	8	8	
Rhinolophus megaphyllus	Eastern horseshoe-bat	Microbat	4	4	
Saccolaimus flaviventris	Yellow-bellied sheathtail-bat	Microbat	10	8	
Scoteanax rueppellii	Greater broad-nosed bat	Microbat	26	24	
Scotorepens orion	Eastern broad-nosed bat	Microbat	74	72	
Vespadelus darlingtoni	Large forest bat	Microbat	8	7	
Vespadelus pumilus	Eastern forest bat	Microbat	7	6	

Scientific name	Common name	Habitat group	Valid records	Quality checked records	Final
Vespadelus regulus	Southern forest bat	Microbat	22	22	
Vespadelus vulturnus	Little forest bat	Microbat	112	107	
Pteropus alecto	Black flying-fox	Flying-fox	1	1	47
Pteropus poliocephalus	Grey-headed flying-fox	Flying-fox	54	46	

Table 12 Datasets to characterise the habitat requirements of iconic species

Dataset	Data source	Method of preparation
(1) Sentinel-2 10 m image (blue, green, red, near infrared bands), with top of atmosphere (sun angle) correction	Copernicus Open Access Hub	A Sentinel-2 multispectral 10 m cloud free image collected on 30 January 2018 was sourced and downloaded from the Copernicus Open Access Hub.
(2) NDVI Jan 2018	Produced for this project from (1) the Sentinel-2 10 m multispectral image	The Normalised Difference Vegetation Index is used to map green (live) vegetation. It is calculated using the formula (NIR – R)/NIR + R). We calculated NDVI using the 10 m Sentinel-2 Jan 2018 image. The NDVI result was then classified into 4 classes using natural breaks. The 4 classes from natural breaks were checked against high-resolution digital air photos collected in 2017 by NSW Land and Property Information, and named in order of increasing green-ness: 'Very Green', 'Moderately Green', 'Sparse green', and 'bare and urban surfaces'. The resulting vegetation green-ness classes were used as inputs to generate cost surfaces for cost distance calculations.
(3) NSW Imagery	NSW Imagery(MapServer)	High-resolution (10 cm) imagery provided by the NSW imagery web service. The most recent imagery available for the Wianamatta–South Creek catchment at the time of study was collected from 24/2/2016 to 03/05/2016.
(4) NSW Landuse 2013	NSW Landuse 2013 dataset	The dataset shows how the landscape of NSW was used for food production, forestry, nature conservation, infrastructure, and urban development, as of 2013.
(5) NSW Roads	Department of Planning and Environment internal data	The Environment and Heritage Group of Department of Planning and Environment maintains a compilation of road mapping. The most recent updates (at the time of this study) within the Wianamatta–South Creek Catchment were completed in 2015.
(6) Urban surfaces January 2018	Produced for this project. Combines information from datasets (1), (3), (4) and (5).	The dataset was produced from (4) the NSW Landuse 2013 data, (3) NSW imagery (2016), (1) the Sentinel image (January 2018) and (5) the NSW Roads dataset. Appendix A, Section A.3 provides details on the sequence of steps for developing the dataset.
(7) Woody Extent and Foliage Projective Cover - SPOT, OEH algorithm, NSW coverage 2011 (Fisher et al 2016).	NSW Woody Vegetation Extent & FPC 2011	A map of woody vegetation extent for NSW for 2011, with 5 m pixels. A full description of the methods can be found in Fisher et al. 2016.

Dataset	Data source	Method of preparation
(8) Woody vegetation 2018	Produced for this project. Combines information from datasets (7), (3) and (4).	The available woody vegetation dataset (7) for 2011 was overlaid on (3) the NSW imagery and (1) the Sentinel image January 2018. Areas that had been recently cleared for urban development were manually removed.
(9) Strahler stream order	Environment, Energy and Science Group of DPIE	This dataset adopts the linework from the NSW Hydro Line Dataset, but with stream order subsequently added to produce the Strahler stream order dataset.
(10) NSW Hydro Area	NSW Hydro Area dataset	The NSW Hydro Area dataset is produced by NSW Land and Property Information, and identifies waterbodies across all of NSW. The dataset is produced at fine scale and identifies waterbodies using air photo interpretation of water and landform features.
(11) Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207 (James 2018).	Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207	Maps PCTs and endangered ecological communities. Community extent data is updated to 2013, condition data was collected pre 1999 and has not been updated. Further detail on map methods and vegetation communities are available from (NPWS 2002). Note that this dataset was revised to remove areas of clearing that had occurred at the time of this present study.
(12) Perennial streams, 3rd order and higher streams, and waterbodies	Produced for this project from datasets (9), (10) and (3)	Identifies waterbodies and streams likely contain water most of the time. Formed by first combining (10) Hydro area and (9) Strahler stream order datasets. Streams were included if they were mapped as perennial or were of Strahler stream order 3 or greater. The dataset was then manually updated to 2016 using (3) the NSW high-resolution imagery to add and remove farm dams.
(13) All streams and waterbodies	Produced for this project from datasets (9), (10) and (3)	Identifies all intermittent streams, waterbodies and dams. Formed by first combining (10) Hydro area and (9) Strahler stream order datasets. The dataset was then manually updated to 2016 using (3) the NSW high-resolution imagery to add and remove farm dams.
(14) Digital Elevation Model (DEM) 5 Metre Grid of Australia	Digital Elevation Model (DEM) of Australia	The Digital Elevation Model (DEM) 5 Metre Grid of Australia derived from LiDAR model represents a national 5 m (bare earth) DEM that has been derived from some 236 individual LiDAR surveys between 2001 and 2015.

Table 13 Water source and cost datasets developed for fauna habitat use groups

Habitat group	Water source dataset	Cost dataset[4]	Data source (cross reference Table 12)
Ground and burrowing frogs	All streams and waterbodies	1 Native vegetation (all PCTs)	NSW State Vegetation Type Map, Vegetation community map 2018
		2 Other very green vegetation	NDVI January 2018
		4 Other green vegetation	NDVI January 2018
		16 Other sparse green vegetation	NDVI January 2018
		1,000 Bare ground and urban surfaces	NDVI January 2018, Urban surfaces January 2018
Tree frogs and riparian vegetation dependent birds	All streams and waterbodies	1 Native woodlands and forests (all woody PCTs)	NSW State Vegetation Type Map, Vegetation community map 2018
		4 Other woody vegetation	Woody vegetation 2018
		16 Other very green non woody vegetation	NDVI January 2018, Woody vegetation 2018.
		32 Other green non woody vegetation	NDVI January 2018, Woody vegetation 2018
		64 Other sparse green non woody vegetation	NDVI January 2018, Woody vegetation 2018
		1,000 Bare ground and urban surfaces	NDVI January 2018, Urban surfaces January 2018
Small wader birds	3rd order and greater streams, perennial streams, and waterbodies	1 Non woody wetland PCT	NSW State Vegetation Type Map, Vegetation community map 2018
		2 Bare ground (not surfaced)	NDVI January 2018, Urban surfaces January 2018
		4 Other green non woody vegetation	NDVI January 2018, Woody vegetation 2018
		1,000 woody vegetation and urban surfaces	Woody vegetation 2018, Urban surfaces 2018
Large wader birds	3rd order and greater streams, perennial streams, and waterbodies	1 Non woody wetland PCT	NSW State Vegetation Type Map, Vegetation community map 2018
		2 Other very green vegetation	NDVI January 2018
		4 Other green vegetation	NDVI January 2018
		16 Other sparse green vegetation	NDVI January 2018
		1,000 Bare ground and urban surfaces	NDVI January 2018, Urban surfaces January 2018
Emergent vegetation dependent and wetland generalist birds	3rd order and greater streams, perennial streams, and waterbodies	1 Emergent vegetation PCTs[1]	NSW State Vegetation Type Map, Vegetation community map 2018
		2 Very green vegetation	NDVI January 2018

Habitat group	Water source dataset	Cost dataset[4]	Data source (cross reference Table 12)
		16 Green vegetation	NDVI January 2018
		32 Sparse green vegetation	NDVI January 2018
		64 Bare ground (not surfaced)	NDVI January 2018, Urban surfaces January 2018
		1000 Urban surfaces	Urban surfaces January 2018
Open water forager birds	3rd order and greater streams, perennial streams, and waterbodies	1 Native vegetation (all PCTs)	NSW State Vegetation Type Map, Vegetation community map 2018
		2 Other very green vegetation	NDVI January 2018
		4 Other green vegetation	NDVI January 2018
		16 Sparse green vegetation	NDVI January 2018
		1,000 Bare ground and urban surfaces	NDVI January 2018, Urban surfaces January 2018
Microbats (except southern myotis)	All streams and waterbodies	1 Microbat PCTs[3] (excluding southern myotis PCTs)	NSW State Vegetation Type Map, Vegetation community map 2018
		16 Other native vegetation (all other PCTs)	NSW State Vegetation Type Map, Vegetation community map 2018
		64 Woody non-native vegetation	NSW State Vegetation Type Map, Vegetation community map 2018, Woody vegetation 2018
		1,000 Bare ground, urban surfaces, and non-native non woody vegetation	NDVI January 2018, Urban surfaces January 2018, NSW State Vegetation Type Map, Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207 (James 2018), Woody Vegetation 2018
Southern myotis	3rd order and greater streams, perennial streams, and waterbodies	1 Southern myotis PCTs[3] with water dependencies[2]	NSW State Vegetation Type Map, Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207 (James 2018)
		4 Other southern myotis PCTs[3]	NSW State Vegetation Type Map, Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207 (James 2018)
		16 Other native vegetation (all other PCTs)	NSW State Vegetation Type Map, Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207 (James 2018)

Habitat group	Water source dataset	Cost dataset[4]	Data source (cross reference Table 12)
		64 Woody non-native vegetation	NSW State Vegetation Type Map, Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207 (James 2018) Woody vegetation 2018.
		1,000 Bare ground, urban surfaces, and non-native non woody vegetation	NDVI January 2018, Urban surfaces January 2018, Woody vegetation 2018, NSW State Vegetation Type Map, Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207 (James 2018)
Flying-foxes	3rd order and greater streams, perennial streams, and waterbodies	1 Flying-fox PCTs[3]	NSW State Vegetation Type Map, Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207 (James 2018)
		16 Other native vegetation (all other PCTs)	NSW State Vegetation Type Map, Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207 (James 2018)
		64 Woody non-native vegetation	NSW State Vegetation Type Map, Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207 (James 2018), NDVI Jan 2018
		1,000 Bare ground, urban surfaces, and non-native non woody vegetation	NDVI January 2018, Urban surfaces January 2018, Woody vegetation 2018, NSW State Vegetation Type Map, Revised Remnant Vegetation of the western Cumberland subregion, 2013 Update, VIS ID 4207 (James 2018).

1. PCTs with emergent vegetation included: PCT 781 Coastal freshwater lagoons of the Sydney Basin Bioregion, PCT 1067 Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, and PCT 837 Forest Red Gum Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain.
2. PCTs with surface water dependencies and associated with southern myotis habitat included: PCT 1067 Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, and PCT 837 Forest Red Gum Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain.
3. Further details of the PCTs selected as suitable bat habitat are provided in Table 14.
4. Numbers are the weighting adopted for habitat suitability in the cost rasters.

Table 14 NSW plant community type (PCT) association with bat habitat

PCT number[1]	Large eared pied bat	Eastern false pipistrelle	Little bentwing-bat	Eastern bentwing-bat	Eastern freetail bat	Southern myotis	Grey headed flying-fox	Yellow-bellied sheathtail-bat	Greater broad-nosed bat
	Chalinolobus dwyeri	*Falsistrellus tasmaniensis*	*Miniopterus australis*	*Miniopterus schreibersii oceanensis*	*Mormopterus norfolkensis*	*Myotis macropus*	*Pteropus poliocephalus*	*Saccolaimus flaviventris*	*Scoteanax rueppellii*
	V1, V2[2]	V2	V2	V2	V2	V2	V1, V2	V2	V2
724	✓	✓	✓	✓	✓	✓	✓	✓	✓
725	✓	✓	✓	✓	✓	✓	✓	✓	✓
830	✓	✓	✓	✓	✓	✓	✓	✓	✓
835	✓	✓	✓	✓	✓	✓	✓	✓	✓
849	✓	✓	✓	✓	✓	✓	✓	✓	✓
850	✓	✓	✓	✓	✓	✓	✓	✓	✓
883	✓	✓	✓	✓	✓	✓	✓	✓	✓
1067	✓	✓	✓	✓	✓	✓	✓	✓	✓
1395	✓	✓	✓	✓	✓	✓	✓	✓	✓

1. PCT number describes the PCT according to the NSW Vegetation Classification Database. See the 'About BioNet Vegetation Classification' webpage, and Table 15 below.
2. Data source: NSW Threatened Species Profile database. V1 = listed as vulnerable in the BC Act. V2 = listed as vulnerable in the EPBC Act.

Table 15 NSW PCT, status, dependency on surface water stores (SWT) association with bat habitat

PCT	Community description	NSW endangered ecological community	EPBC name	SWT
724: Broad-leaved Ironbark - Grey Box - Melaleuca decora grassy open forest on clay/gravel soils of the Cumberland Plain, Sydney Basin Bioregion	103 – Shale/Gravel Transition Forest	Shale Gravel Transition Forest in the Sydney Basin Bioregion	Shale Gravel Transition Forest in the Sydney Basin Bioregion	N
725: Broad-leaved Ironbark - Melaleuca decora shrubby open forest on clay soils of the Cumberland Plain, Sydney Basin Bioregion	3 – Cooks River Castlereagh Ironbark Forest	Cooks River/Castlereagh ironbark forest in the Sydney Basin Bioregion	Cooks River/Castlereagh ironbark forest in the Sydney Basin Bioregion	N
781: Coastal freshwater lagoons of the Sydney Basin Bioregion and South East Corner Bioregion	36 – Freshwater Wetlands	Freshwater wetlands on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Y
830: Forest Red Gum - Grey Box shrubby woodland on shale of the southern Cumberland Plain, Sydney Basin Bioregion	14 – Moist Shale Woodland	Moist Shale Woodland in the Sydney Basin Bioregion	Western Sydney Dry Rainforest and Moist Woodland on Shale	N
835: Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion	11 – Alluvial Woodland	River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Y
835: Forest Red Gum - Rough-barked Apple grassy woodland on alluvial flats of the Cumberland Plain, Sydney Basin Bioregion	12 – Riparian Forest	River-flat eucalypt forest on coastal floodplains of the NSW North Coast, Sydney Basin and South East Corner bioregions	Not listed	Y
849: Grey Box - Forest Red Gum grassy woodland on flats of the Cumberland Plain, Sydney Basin Bioregion	10 – Shale Plains Woodland	Cumberland Plain Woodland in the Sydney Basin Bioregion	Cumberland Plain Woodland in the Sydney Basin Bioregion	N
850: Grey Box - Forest Red Gum grassy woodland on shale of the southern Cumberland Plain, Sydney Basin Bioregion	9 – Shale Hills Woodland	Cumberland Plain Woodland in the Sydney Basin Bioregion	Cumberland Plain Woodland in the Sydney Basin Bioregion	N
877: Grey Myrtle dry rainforest of the Sydney Basin Bioregion and South East Corner Bioregion	13 – Western Sydney Dry Rainforest	Western Sydney Dry Rainforest in the Sydney Basin Bioregion	Western Sydney Dry Rainforest in the Sydney Basin Bioregion	Y

PCT	Community description	NSW endangered ecological community	EPBC name	SWT
883: Hard-leaved Scribbly Gum - Parramatta Red Gum heathy woodland of the Cumberland Plain, Sydney Basin Bioregion	6 – Castlereagh Scribbly Gum Woodland	Castlereagh Scribbly Gum Woodland in the Sydney Basin Bioregion	Castlereagh Scribbly Gum Woodland in the Sydney Basin Bioregion	N
1067: Parramatta Red Gum woodland on moist alluvium of the Cumberland Plain, Sydney Basin Bioregion	4 – Castlereagh Swamp Woodland	Castlereagh Swamp Woodland	Not listed	Y
1395: Narrow-leaved Ironbark - Broad-leaved Ironbark - Grey Gum open forest of the edges of the Cumberland Plain, Sydney Basin Bioregion	1 – Shale Sandstone Transition Forest (Low Sandstone Influence)	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	N
1395: Narrow-leaved Ironbark - Broad-leaved Ironbark - Grey Gum open forest of the edges of the Cumberland Plain, Sydney Basin Bioregion	2 – Shale Sandstone Transition Forest (High Sandstone Influence)	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	Shale Sandstone Transition Forest in the Sydney Basin Bioregion	N

Data sources: NSW BioNET; *Interpretation Guidelines for the Native Vegetation Maps of the Cumberland Plain* (NPWS 2002)

Appendix G – Literature review

This appendix contains 2 main sections of literature reviewed. The first section lists literature that informed the methods for modelling of habitats of functions groups of iconic species of waterbirds, water dependent bats and frogs. The second section lists the literature that informed the habitat requirements of specific species.

G.1 Methods for developing datasets of habitats for functional groups of water dependent iconic species

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G.2 Habitat requirements of waterbirds, water dependent bats and frogs

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